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BEHAVIOR OF CERTAIN RADIONUCLIDES RELEASED INTO FRESH-WATER ENVIRONMENTS

Albert G. Friend, et al

Public Health Service
Washington, D. C.

June 1965

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ENVIRONMENTAL HEALTH SERIES
Radiological Health

BEHAVIOR OF CERTAIN RADIONUCLIDES RELEASED INTO FRESH-WATER ENVIRONMENTS

Annual Report 1959-1960

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

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BEHAVIOR OF CERTAIN RADIONUCLIDES RELEASED INTO FRESH-WATER ENVIRONMENTS

Annual Report 1959–1960

Albert G. Friend
Albert H. Story
Croswell R. Henderson
Kenneth A. Busch

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ABSTRACT

Radionuclides from various sources, including facilities that produce, process, and handle nuclear material, are entering the fresh-water environment. The Service's Division of Radiological Health, in cooperation with the Atomic Energy Commission, has conducted a number of investigations of streams below atomic energy installations. Two such studies, one on the Mohawk River near Knolls Atomic Power Laboratory, and the other on the Clinch and Tennessee Rivers near the Oak Ridge National Laboratory, are presented in this document. In general, the results show that all segments of the aquatic environment related to these rivers contain measurable quantities of manmade radionuclides. The results of some uptake studies, carried out in a DRH laboratory, are included to supplement the river studies and to aid in interpreting the results obtained in the field.

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INTRODUCTION

Waste materials containing radionuclides are discharged from atomic energy installations and from facilities processing and using radioactive isotopes. While there have been relatively few reports on the ultimate fate of the radionuclides when released into the environment (*1, 2, 3, 4*) many studies indicate changes in gross activity but neglect almost entirely changes in the activity of specific radionuclides in the mixture of radioactive materials discharged. Furthermore, the effects of dilution and decay and of the chemical or biological aspects of precipitation, ion exchange, adsorption, absorption, assimilation, or metabolism of specific radioactive contaminants have not been evaluated in a manner that permits reasonably accurate predictions of the "self purification" of streams or other media.

The movement in the environment of radionuclides of the greatest public health significance can be determined after isolation from other radioactive materials and, more particularly, from the large mass of stable material associated with them. Procedures and techniques for concentration, separation, identification, and measurement of radionuclides in water have been previously presented (*5*).

Two approaches might be used to determine the fate of radionuclides released to the hydrosphere. The first utilizes an uncontaminated stream having a normal biota "spiked" with single or multiple radioisotopes, and determines the concentration of the added isotopes at several points downstream. If reductions in activity not explained in terms of dilution or decay are noted, the various components of the environment—soil, plankton, vegetation, fish, etc.—would be assayed to determine to what extent each contributed in reducing the level of activity in the water. The second approach utilizes selected stream environments located below atomic energy installations and known to receive specific radionuclides. Analyses of samples collected well upstream from the point of discharge of the waste materials would determine baseline levels while analyses of samples collected at several downstream points would be used to follow movement of isotopes released. This second approach is more complex and involves more analytical work, owing to lack of control by the investigator over the quantity and nature of wastes discharged during the study. It was, however, chosen as the basis for our study since the wastes involved were from a plant under operating conditions.

Four field trips were made during the period covered by this report. Results of two trips, one to the Mohawk River in September and October of 1959 and one to the Clinch River in February 1960, are discussed in this report. Analyses of results of the other two trips, one to each of the above areas, are not complete and will be included in the next annual report.

To supplement the data obtained from these field studies, laboratory experiments were designed to obtain a better picture of the effect of various parameters upon the uptake of radionuclides. Thus, some of the uncontrolled aspects of field work might be explained.

SECTION I: MOHAWK RIVER STUDY—SEPTEMBER AND OCTOBER 1959

Introduction to Study Area

AREA DESCRIPTION

From its headwaters in the woodlands north of Rome, the Mohawk River flows south to the Delta Reservoir and then to Rome. Here the river turns abruptly to the east and, after flowing past Utica, Little Falls, Amsterdam, and Schenectady, joins the Hudson River at Cohoes, approximately 175 miles downstream (fig. 1–1).

In some regions the river serves as a part of the Erie Barge Canal system. There are 20 locks in the reach of the Mohawk between Rome and Cohoes. Seven are downstream from the Knolls Atomic Power Laboratory (KAPL). Some dams at the lock sites are movable and are raised during winter to permit passage of ice and debris. KAPL wastes are discharged into the Niskayuna Pool, formed by Vischer Ferry Dam, 1.7 miles below KAPL. The dam forms a yearlong barrier and creates a permanent pool. The average elevation of the Niskayuna Pool is about 210 feet above mean sea level.

HYDROLOGIC DATA

The flow pattern of the Mohawk River during most of the year is highly regulated by manmade controls. The navigational locks and attendant dams transform the river into a series of closely controlled, terraced pools. Periodic dredging provides a channel in much of the river to a depth of 16 feet or greater. The last of the present regulatory devices, the Schoharie Reservoir, was finished in 1926. Consequently, only hydrologic data since 1927 have been used in this study.

The catchment area of the Mohawk River drains approximately one-fifteenth of the State of New York. In this basin, at least 300 tributaries flow into the Mohawk River. Of principal importance are East Canada Creek, West Canada Creek, and Schoharie Creek. In addition, three large reservoirs feed the Mohawk. Their combined capacities are 8.7 by 10^9 cubic feet. This water is used both for water supply and for barge canal feeders during periods of low flow. Tributaries entering the river below KAPL are small and contribute a negligible amount to the total flow.

In a stream receiving radioactive wastes at a constant rate, the most relevant flow value is the minimum daily flow. Table 1–1 shows the minimum daily flows of the Mohawk at Cohoes for the years 1935–51. A probability plot of these data shows that the minimum daily flow that might be expected at Cohoes once in 50 years is about 127 c.f.s. (fig. 1–2). Owing to the number of control features on the river, however, daily flows are almost meaningless, since they can be and are varied to suit the needs of river users.

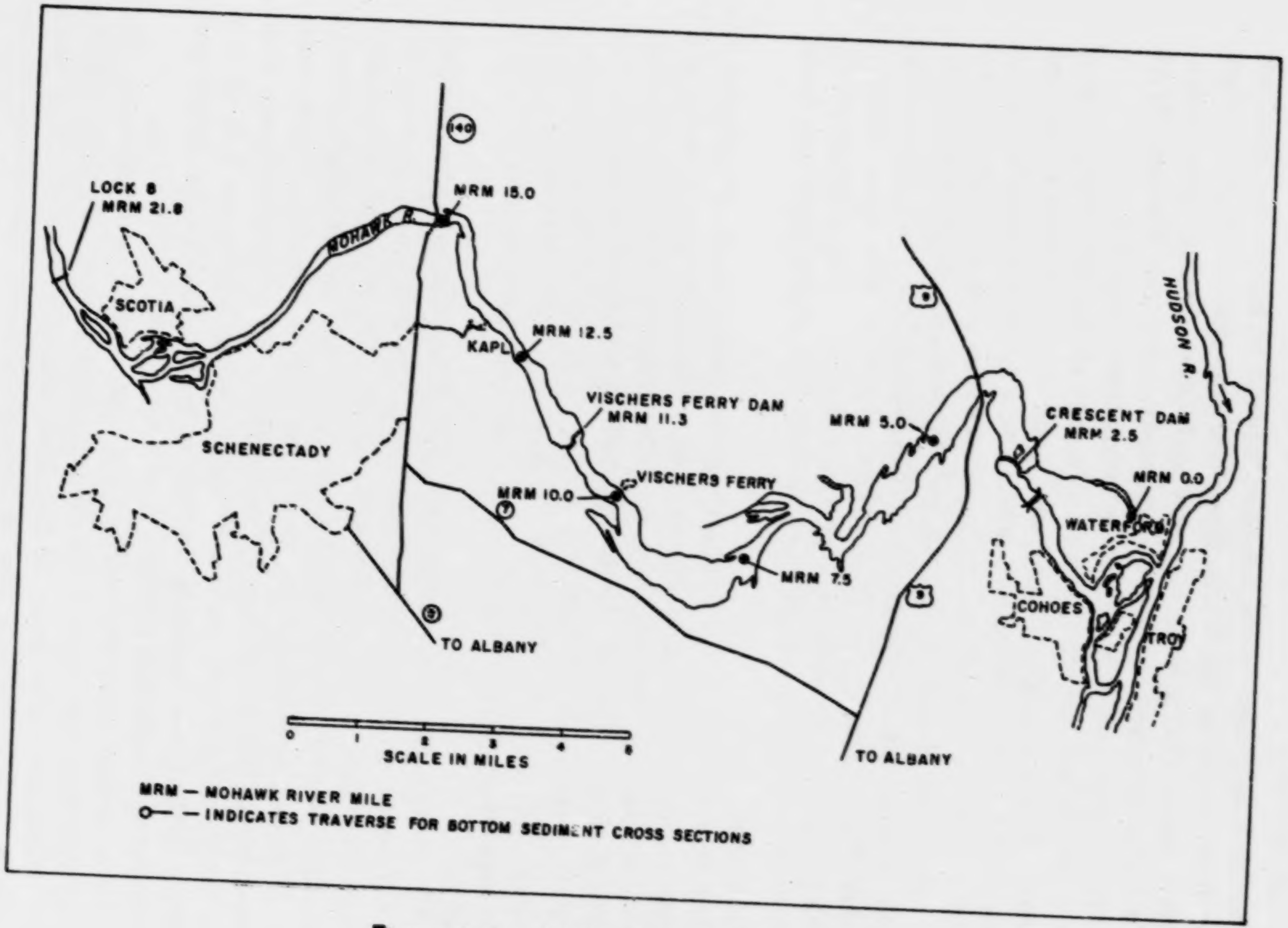
LOCK 8
MRM 21.8
SCOTIA
MOHAWK R.
SCHENECTADY
140
MRM 15.0
KAPL
MRM 12.5
VISCHERS FERRY DAM
MRM 11.3
MRM 10.0
VISCHERS FERRY
7
MRM 7.5
MRM 5.0
9
TO ALBANY
TO ALBANY
CRESCENT DAM
MRM 2.5
MRM 0.0
WATERFORD
COHOES
TROY
HUDSON R.
0
1
2
3
4
5
SCALE IN MILES
MRM — MOHAWK RIVER MILE
O— — INDICATES TRAVERSE FOR BOTTOM SEDIMENT CROSS SECTIONS

Figure 1–1. Mohawk River Study Area

Maximum flows on the river occur in April, probably from melting ice and snow, and minimum flows occur in August, September, and October. For the period 1927–55, the maximum monthly mean flow was 4,150 c.f.s., and the minimum monthly mean flow in August was about 600 c.f.s. at Cohoes. The minimum, median, and maximum mean monthly flows at this station are shown in figure 1–3.

Table 1–1. Minimum Daily Flows—Mohawk River at Cohoes, 1935–51

Rank	Year	Month and day	Single day cfs
1	1941	Aug. 10	173
2	1942	Sept. 2	194
3	1938	Sept. 1	237
4	1946	Sept. 15	241
5	1947	Oct. 18	242
6	1936	July 16	244
7	1949	Aug. 20	278
8	1939	Aug. 29	317
9	1944	Aug. 28	338
10	1943	Oct. 9	368
11	1937	Oct. 1	375
12	1940	Aug. 24	402
13	1948	Oct. 1	439
14	1950	Aug. 24	687
15	1945	Aug. 19	704
16	1935	Aug. 22	733
17	1951	Aug. 9	1,077

The flow at Cohoes is not necessarily the precise flow at KAPL, 15 miles upstream. However, Cohoes is the first point where an urban water supply is obtained from the river. The river discharge at Cohoes seems, therefore, to be a reasonable flow to use, especially since modern records are not available for flows at any other point near KAPL, and this is the dilution that may be expected at the first water intake below KAPL.

METEOROLOGIC DATA

The climate of the Mohawk River Valley ranges from moderately harsh winters to moist, hot summers. The winter season typically extends from November through April, and snow covers average up to 5 inches in March. Ice formation on the river is common in winter months and occasional ice jams result. The KAPL area has never been imperiled, although 3 feet of backwater was recorded at KAPL in 1954 owing to an ice jam at Vischer Ferry Dam.

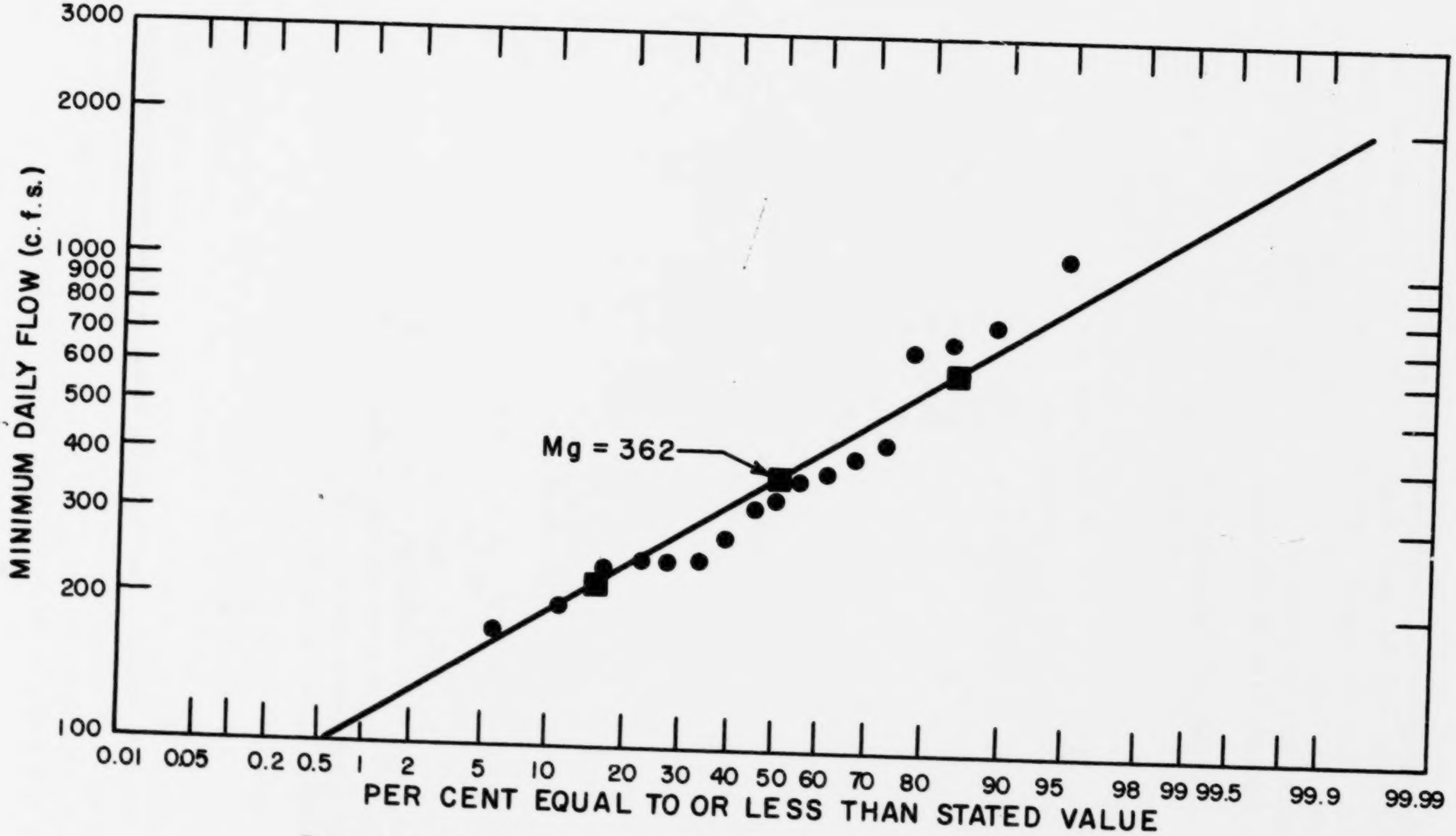

Figure 1–2. Probability Plot of Minimum Daily Stream Flows Observed Annually in the Mohawk River at Cohoes

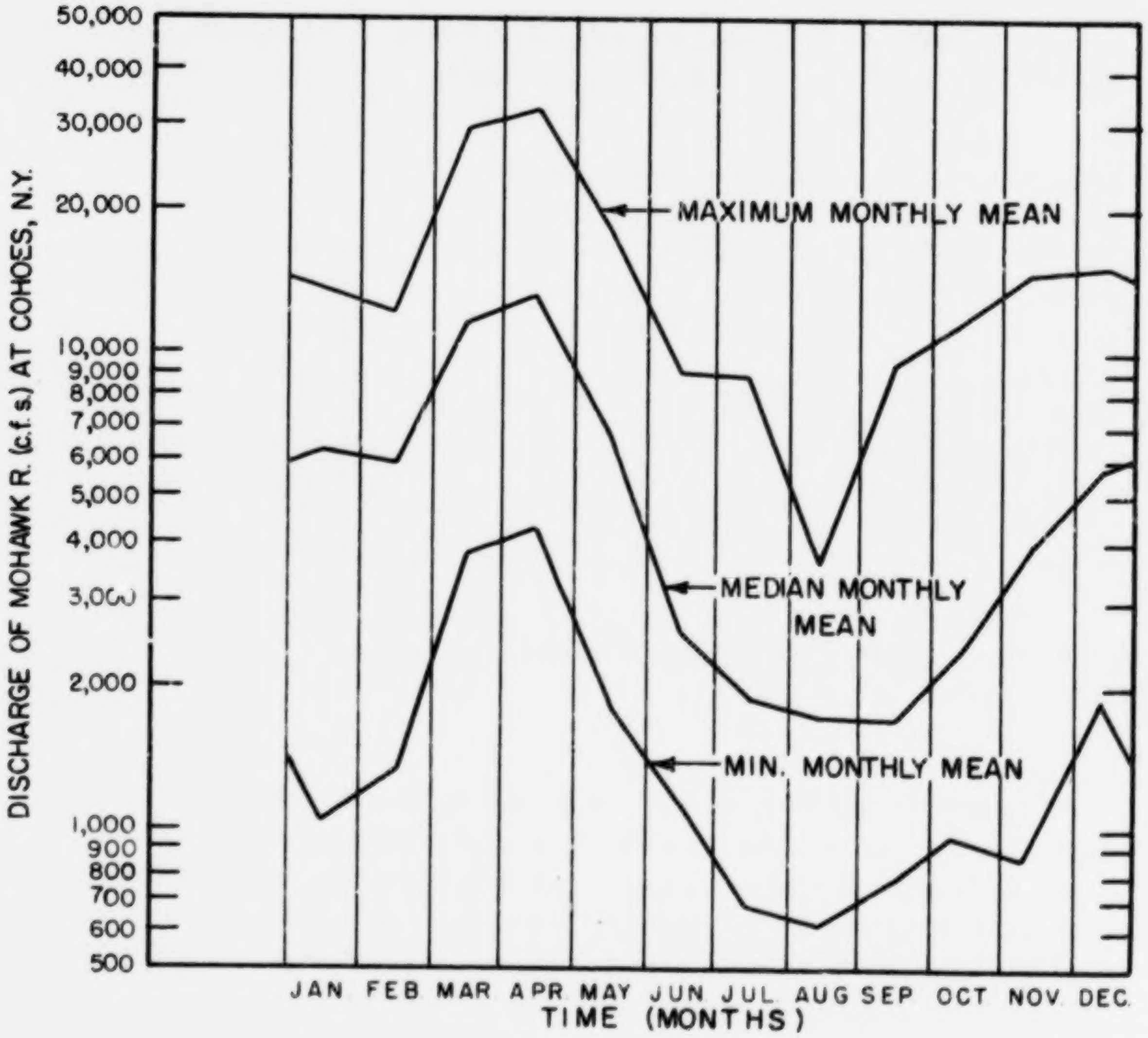

Figure 1–3. Maximum, Median, and Minimum Mean Monthly Flows of the Mohawk River at Cohoes, 1927–1955

Long-term mean precipitation generally varies from a low of 1 inch in January to a high of 4 inches in May. Table 1–2 lists the long-term mean rainfall values for the Albany Airport, which is near KAPL.

GEOLOGIC DATA

The upper Mohawk River lies primarily in a limestone region, and quantities of water are carried underground through faults and crevices. The bulk of the riverbed, however, is situated in shales and schists. In the vicinity of KAPL and in the Hudson River Valley, the Normanskill shales of the Ordovician Age account for most of the river bedrock. In portions of Albany County, however, the bedrock underlies the Snake Hill formation. About 11 miles below KAPL, near the Route 9 Bridge, the river has eroded a gorge through the flat-lying shales to a depth of 100 to 200 feet. This cut was made in relatively recent geologic times.

Table 1-2. Long-Term Monthly Mean Precipitation at Albany Airport

Month	Inches
January	1. 11 (low)
February	2. 03
March	2. 33
April	2. 61
May	3. 80 (high)
June	3. 37
July	3. 30
August	2. 89
September	3. 15
October	2. 21
November	2. 69
December	2. 17

Note: Data courtesy U.S. Weather Bureau.

In general, the silts of the river and adjacent clays reflect shale deposits that lie within 10 miles north of the river. This condition has resulted from glacial action. As a rule, the tributaries from the north flow into the river across the Trenton limestones into the granites and gneisses of the Adirondack Region. Tributaries from the south flow across Hamilton shales and the upper and lower Helderberg groups.

BIOLOGIC DATA

From the biological standpoint, the Mohawk River, in the study area, is a fairly rich stream. There is a large, mixed, warm-water fish population, including rough, forage, food, and game species. Carp, suckers, and bullheads, mostly bottom feeders, are abundant. The anadromous alewife and white perch are abundant and spawn prolifically in this area. Largemouth and smallmouth bass, rock bass, yellow perch, and several species of sunfish are among predominant game species, and spawn in this section of the river. Forage species are abundant, including bluntnose minnows, several species of shiners, and darters.

The bottom fauna population is sparse. In bottom-mud samples, there are few animals, probably because of the large amount of oil mixed with the mud. Large numbers of scuds, midge larvae, and damselfly nymphs grow among the filamentous algae, arrowroot, pondweed, and water chestnuts along the shoreline and in shallow water areas. In some of the rocky, fast-flowing water areas below dams, snails and crayfish are numerous.

In the Mohawk, phytoplankton are fairly abundant, and in some areas large populations of zooplankton, mostly small crustaceans, have been observed. Plankton are much less abundant in the Hudson River.

WATER USES

The Mohawk River in the vicinity of KAPL is used for domestic and industrial water supply, for bathing, fishing, pleasure boating, navigation, transportation, waste disposal, power development, and fire protection. Table 1–3 shows the water uses recommended by the Mohawk River Drainage Basin Survey Series Report No. 2 for the reach of the river under study.

Currently the river is used to a very limited extent for bathing or fishing, probably because of pollution. While fish populations are fairly high, including game species, there is no commercial fishing and little sport fishing. It is reported that the fish are tainted and not suitable for consumption. The New York Conservation Department carries out a summer netting program, removing fish to areas more attractive to fishermen.

SAMPLING STATIONS

General sampling areas are indicated in figure 1–1 by the numbers 1, 2, 3, etc.; mileages from the KAPL outfall are shown under these numbers. Specific sampling locations are indicated by the single capital letters adjacent to the crosshatch areas and may represent areas from which 1 to 50 samples were collected. An attempt was made to collect the same types of samples at each station to compare radionuclide levels in each with similar samples collected at other stations.

Station 1 was upstream from lock 8, approximately 9 miles above the KAPL outfall, beyond the influence of KAPL discharges. Nuclide concentrations in the media tested from this station were considered as baseline levels. At the time of sample collections at this station, there was no overflow at the damsite; all the water was being released through the barge canal. Sample location A was a small cove on the south bank of the river, approximately 4,500 feet upstream from the dam. Sample location B was on the south bank of the river immediately adjacent to the locks. In general, the river at station 1 was very slow-moving, with only slight currents near the south shore.

Station 2 was at the KAPL outfall, a distance of approximately 1.7 miles upstream from Vischer Ferry Dam. Here the river was quiescent. Sample location C was immediately below the KAPL outfall at the boat dock on the KAPL reservation. Sample location D was on the north bank of the river about one-half the distance between the boat dock and the dam. Sample location E was immediately upstream from the dam at about midriver.

Table 1–3. Classification of Water Uses Recommended by the Mohawk River Drainage Basin Survey

Miles downstream from KAPL	Boundary	Character of district	Condition of water	Present usage	Best usage
0–1.7	Lock 9 to lock 7	Populated and industrial areas, open fields, woodland	Polluted	Industrial wastes, sewage disposal, industrial water supply, transportation	Bathing
1.7–9.6	Lock 7 to 1 mile above Rt. 9 Bridge over Mohawk	Woodland, open fields	Polluted	Transportation, fishing, power development	Bathing
9.6–12.1	1 mile above Rt. 9 Bridge over Mohawk to Crescent Dam	Woodland, open fields, farmland	Polluted	Water supply, bathing, transportation, fishing	Water supply
12.1–13.0	Crescent Dam to first dam above Cohoes Falls	Woodland, open fields	Polluted	Water supply, fishing, power development	Water supply
13.0–15	First dam above Cohoes Falls to mouth	Populated and industrial area, open fields, farmland	Polluted	Industrial and sanitary waste disposal, power development, fishing	Fishing

KAPL discharges its wastes underwater, about 40 feet from the shore. The amount of mixing of effluent and river water that would occur in the pool at this stage of the river would be minimal. However, it was assumed that, since water from this pool is discharged through turbines at a powerhouse at the northern end of Vischer Ferry Dam, the effluent from the outfall would, in general, flow in the direction of the turbine intakes.

Station 3 was immediately below Vischer Ferry Dam. Samples taken at location F were from rapidly flowing water in the tailrace from the turbines. Sample location G was in a small cove close to the dam but south of the main flow of the tailrace water. Sample location H was at the confluence of the tailrace and the main river. Owing to scour, no samples of bottom mud could be collected in the main channel; however, pea-sized shale was collected.

Station 4 was in the upper reaches of the pool formed by Crescent Dam at station 5 and was approximately 6.1 miles downstream from KAPL. Sample location I was on the north bank of the river, where cattails and water chestnuts grow profusely. Sample location J was on the south bank of the river at a private boat dock. Here the river narrows appreciably. Sample location K was immediately downstream from location J and on the same side. The river in this stretch has a deep mud bottom, resulting probably from scour at station 3 with subsequent deposition in this area.

Station 5 was immediately below Crescent Dam and approximately 12.1 miles downstream from the KAPL effluent outfall. A power station is also at this point and the water moves rather rapidly in the sampling area. Sample location L was immediately below the dam in the tailrace from the turbine. Sample location M was approximately 50 yards to the east of location L, in a small cove where the water was still and quite deep.

Station 6 was located on the Hudson River upstream from the point of confluence with the Mohawk River. Here the river was in pool and only slight currents were noted. Sample locations N and O were located on the east bank of the Hudson River approximately 50 feet from the shore. A paper mill was apparently discharging wood fibers into the stream above this area, since the nets were covered with this refuse after being out for approximately 12 hours.

Station 7 was at the locks on the Hudson River at Troy. Sample location P was upstream from the locks, where the river was in pool. Location Q was approximately one-half mile below the dam in the tidewater area. Although the water here was fresh, the river level was influenced by the tides and fluctuated 4 to 5 feet. The water was of poor quality, owing to the discharge of wastes by Cohoes, Troy, and other cities upstream.

Sample Collection, Preparation, and Analysis

WATER SAMPLES

Water samples were collected on a continuous basis. Where possible, the samplers [1] were located near spillways or in narrow channels, or in other locations where water had been mixed thoroughly and representative samples could be obtained. In some instances (stations 4 and 6), it was not possible to use the most desirable location owing to lack of access to the best site. The samplers collected about 2 gallons of water per 24-hour period. Owing to the low flow velocity in the collecting tube, a representative sample of suspended matter in the water could not be collected by this method alone. Consequently, the inlet tube was in a 250-milliliter polyethylene bottle into which the water first flowed through an opening in the side and was then lifted to the 2-gallon water-sample bottle. The suspended matter too heavy to be lifted by the pump settled out in the 250-milliliter bottle. When the water-sample containers were changed, the contents of this polyethylene bottle were combined with the water sample. It was assumed that by this method a representative river-water sample was collected. Samples were composited at the rate of 1 liter per day for a total sample volume of 10 liters. For gamma analysis, the 10-liter sample was reduced by evaporation to 3½ liters and counted in a well-type beaker. The KAPL effluent sample was composited at the rate of 100 milliliters per day for a final volume of 1 liter and this was sent for gamma analysis without further treatment. Results are expressed in picocuries per liter of sample.

---

[1] The samplers used for collection of water samples are battery operated, manufactured by Brailsford and Co., Rye, N.Y.

Table 1–4 shows the results of chemical and physical analyses of the Mohawk River water.

Table 1–4. Concentration Ranges of Mineral Constituents for Mohawk River at Vischer Ferry Dam, October 1951—September 1953

Factor	Median	Low	High	Units
Specific conductivity	235	126	384	micromhos
pH	7.4	7.0	7.6	(monthly mean)
Color	12	2	45	
Dissolved solids	143	82	183	ppm
Hardness	108	53	125	ppm (as $CaCO_3$)
Hardness	22	10	41	ppm (non-carbonate)
SiO_2	5.1	0.4	8.7	ppm
Al	0.1	0.00	0.2	ppm
Fe	0.01	0.00	0.21	ppm
Mn	0.00	0.00	0.01	ppm
Cu	0.00	0.00	0.23	ppm
Zn	0.00	0.00	0.08	ppm
Ca	32.0	14.0	40	ppm
Mg	4.8	2.0	8.8	ppm
Na	5.0	2.2	14	ppm
K	1.3	0.3	2.3	ppm
Li	0.2	0.1	0.5	ppm
HCO_3	96	52	116	ppm
SO_4	25	15	44	ppm
Cl	6.5	1.1	59	ppm
F	0.1	0.0	0.3	ppm
NO_3	2.0	0.6	3.4	ppm
PO_4	0.0	0.0	0.6	ppm

BOTTOM SEDIMENTS

Bottom muds were collected at each station. The method of sampling depended on the conditions of the stream bed at the particular sampling point. In general, samples were taken from the bottom, at or near the channel, by means of a Petersen dredge. The sample at station 2, however, was not taken from the channel but from a boat dock about 40 feet below the KAPL outfall. At station 1, the sample was taken just above the dam; at station 3 from the channel, about 2,000 feet below the powerhouse, on the northern end of Vischer Ferry Dam. The sample at station 3 was not mud but pea-sized shale particles. The samples from stations 4 and 5 were taken from outside the channel because at these points the water was too deep. The sample at station 4 was taken about 500 feet east of Albert's Pier on the same side of the river; at station 5, about 1,000 feet below the powerhouse on the south end of Crescent Dam; at station 6, about 1,000 feet upstream from the water samplers; at station 7, about 1,500 feet below the dam and about 100 feet from the west shore.

A 2-foot core sample of bottom mud was collected at station 2 directly above Vischer Ferry Dam.

Bottom-mud samples were placed in plastic containers for gamma scanning. Results are expressed in picocuries per kilogram of wet weight.

AQUATIC BIOTA

The different types of aquatic biological samples collected in the study area were plankton, filamentous algae, vascular plants, bottom animals, and fish. A sample of hard-shell clams (*Venus mercenaris*) was collected by the New York Department of Health from the ocean area near the mouth of the Hudson River.

Plankton samples were collected by towing a No. 20 (173 meshes per inch) silk bolting-cloth net back and forth across the river. Cross-sectional water samples were taken at the same time to obtain quantitative information on plankton. One 5-liter sample was taken and preserved with thimerosal for a direct strip count in the laboratory. Individual 2-gallon samples were collected and preserved in 5-percent formaldehyde solution. From the latter two samples, 5-liter portions were centrifuged in a Foerst centrifuge and the air-dry and ashed weights of the plankton obtained. For volume measurements, 1-liter samples were centrifuged and measured in a graduated centrifuge tube. The numbers, weights, and volumes of plankton samples are shown in table 1–5. At most stations, in both June and September, the phytoplankton populations were about 55 percent diatoms, 30 percent green algae, and 15 percent blue-green algae. The proportion of greens and blue-greens was much higher at station 2 in both sampling periods. While the plankton counts were higher in September, the weights and volumes were larger in June. This was probably due to the predominance of the very small diatom (*Cyclotella*) in September. Larger diatoms (*Melosira* and *Asterionella*) were predominant in June and larger zooplankton forms were more abundant. Plankton were very sparse in the Hudson River.

No attempt was made to obtain quantitative information on filamentous algae or vascular plants. Green algae (*Cladophora* sp.) were abundant along the shoreline and grew in masses on vegetation and submerged objects. Vascular plants, including arrowroot (*Sagittaria*), pondweed (*Potamogeton crispus*), and water chestnuts (*Trapa natans*), were abundant along the shoreline; large masses of water chestnuts also grew in deeper water areas. Several large floating mats of water lily (*Nymphoides peltatum*) were found in the Hudson River at station 6. Samples of filamentous algae and vascular plants were preserved in 5-percent formaldehyde solution and returned to the laboratory for further processing.

Table 1–5. Comparison of Plankton Counts for Mohawk River, June and September 1959

Station	Phytoplankton (number per ml)		Total plankton					
			Weight mg/l				Volume per ml	
			Air dried		Ashed			
	June	Sept.	June	Sept.	June	Sept.	June	Sept.
1	3, 201	5, 160	14	7	11	2	[a]–	0. 09
2	2, 206	2, 154	13	6	10	3	0. 10	0. 06
3	—	5, 910	—	15	—	9	—	0. 10
4	2, 662	7, 272	17	9	14	7	0. 16	0. 10
5	1, 647	7, 550	24	14	21	11	0. 40	0. 07
6	—	175	—	3	—	2	—	0. 02
7	—	1, 780	—	6	—	4	—	0. 11

[a] Values below limit of detectability.

Fish samples were collected at all stations and arbitrarily divided into two groups, small fish and large fish. The small fish consisted of young of the year of the larger species and adults and young of small species of which the adults normally weighed less than 20 grams each. Small fish were collected, usually along shallow margins of the stream and in small coves, by means of 10- and 30-foot minnow seines having ⅛- and ¼-inch mesh. Large fish were mostly collected with 1-, 2-, and 3-inch gill nets set overnight and across the channel in water 5 to 15 feet deep. The species of small and large fish collected at each station are shown in tables 1–6 and 1–7. Those

Table 1–6. Small Fish Samples Collected from Mohawk River and Identified by Species and Station

Common name	Scientific name	Station locations 1	2	3	4	5	6	7
1. Alewife Y	*Alosa pseudoharengus*	✓	✓	✓	✓	✓	✓	✓
2. Blacknose dace	*Rhinichthys atratulus*	✓						
3. Bluegill Y	*Lepomis macrochirus*		✓	✓	✓	✓		
4. Bluntnose minnow	*Pimephales notatus*	✓	✓	✓	✓	✓		
5. Brown bullhead Y	*Ictalurus nebulosus*	✓	✓			✓		
6. Carp Y	*Cyprinus carpio*	✓			✓			
7. Creek chub	*Semotilus atromaculatus*	✓	✓					
8. Fallfish Y	*Semotilus corporalis*	✓						✓
9. Golden shiner Y	*Notemigonus crysoleucas*	✓	✓	✓	✓	✓	✓	✓
10. Goldfish Y	*Carassius auratus*		✓		✓		✓	
11. Johnny darter	*Etheostoma nigrum*	✓	✓	✓	✓	✓	✓	
12. Banded killifish Y	*Fundulus diaphanus*				✓			
13. Largemouth bass Y	*Micropterus salmoides*	✓	✓	✓	✓	✓		
14. Logperch	*Percina caprodes*			✓				
15. Pumpkinseed Y	*Lepomis gibbosus*	✓	✓	✓	✓	✓	✓	
16. Emerald shiner	*Notropis atherinoides*	✓		✓		✓		
17. Rock bass Y	*Ambloplites rupestris*	✓	✓	✓		✓		
18. Satinfin shiner	*Notropis analostanus*	✓						
19. Smallmouth bass Y	*Micropterus dolomieui*	✓	✓					
20. Spotfin shiner	*Notropis spilopteris*		✓			✓		✓
21. Spottail shiner	*Notropis hudsonius*	✓	✓	✓	✓		✓	✓
22. Trout-perch	*Percopsis omiscomaycus*				✓			
23. White crappie Y	*Pomoxis annularis*				✓			
24. White perch Y	*Roccus americana*			✓				
25. White sucker Y	*Catostomus commersoni*			✓				
26. Yellow perch Y	*Perca flavescens*			✓	✓	✓		

Note: Nomenclature from reference *6*.
Y indicates young of the year and successful spawning of this species.

Table 1–7. Large Fish Samples Collected from Mohawk River and Identified by Species and Station

Common name	Scientific name	Station locations 1	2	3	4	5	6	7
1. Alewife	*Alosa pseudoharengus*		✓	✓		✓		
2. Brown bullhead	*Ictalurus nebulosus*		✓			✓		
3. Carp	*Cyprinus carpio*	✓	✓			✓		
4. Fallfish	*Semotilus corporalis*			✓				
5. Golden shiner	*Notemigonus crysoleucas*						✓	✓
6. Pumpkinseed	*Lepomis gibbosus*						✓	✓
7. Northern hog sucker	*Hypentelium nigricans*			✓				
8. Northern redhorse	*Moxostoma macrolepidotum*			✓				
9. Walleye	*Stizostedion vitreum*					✓		
10. White perch	*Roccus americana*						✓	✓
11. White sucker	*Catostomus commersoni*	✓		✓	✓			✓
12. Yellow perch	*Perca flavescens*		✓	✓	✓	✓	✓	✓

Note: Nomenclature from reference *6*.

marked with Y were young of the year and represent successful spawning of the species.

All biota samples were ashed at 450° C. for gamma analysis. With the exception of fish, duplicate samples from the same station were combined and prepared as one sample.

The first step in the preparation of fish was to separate them into various species according to station. When individual small fish of a single species weighed more than 100 grams, they were processed as separate samples. When small fish weighed less than 100 grams each, composite samples were prepared by combining them into two groups. The first group consisted of the filter feeders, which normally strain organisms from the mud or water and can be expected to contain considerable quantities of mud and vegetation; the other group consisted of sight feeders, which feed on individual organisms, usually insect larvae or other fish. Large fish were prepared whole as separate samples; a few, however, were separated into six parts: flesh and skin, bones, scales, intestinal contents, liver, and the remainder of the viscera.

Snails were processed as whole organisms.

ARTIFICIAL MEDIA

Sampling of water for the determination of low concentrations of radionuclides is a difficult and often unrewarding task. For this reason, the Radiological Health Research Activities Program is interested in the development of artificial media that can be placed in water to concentrate nuclides for easy, accurate determination.

On this field trip, a few of the media discussed in the literature were tested as concentrators of nuclides under field conditions. The four media were spinach, live algae, tea, and cation exchange resins prepared as follows:

Fresh spinach was oven-dried at 103° C. overnight and soaked in a thimerosal solution to prevent bacterial growth and decomposition when placed in the stream. Samples of this preserved, dried spinach, each weighing 33 grams, were then packed in perforated ½-pint polyethylene bags and stored in distilled water for use. Commercial tea was soaked in distilled water for 24 hours to leach out color, preserved in thimerosal, and packaged in ¼-pound samples for use.

Live algae (*Pithophora*) grown in laboratory aquaria to insure freedom from silt, were weighed out in 20-gram samples and packaged in the same manner as the previous samples. For transportation to the field, these algae were placed in oxygenated, distilled water in a polyethylene bag. Forty grams of Dowex-50 in the Ca^{++} form were packed in individual columns equipped with stopcocks at the lower end to control flow.

Upon arrival, duplicate samples of the biological materials were placed in the river adjacent to the water samplers where they remained for the duration of the survey. Two-liter water samples, collected at each station daily, were composited into seven 20-liter samples and passed through individual cation-exchange resin columns. At the end of the field trip, all samples were collected and returned to the laboratory for nuclide analyses.

METHOD USED FOR QUANTITATING GAMMA SPECTRA

The method used for calculating the concentration of gamma emitters consisted of plotting the data from the gamma spectrometer on semilog paper, rounding off the pertinent peaks to approximate a normal distribution curve, drawing a slanted line parallel to the background curve at the base of these peaks, and then estimating the net counts found between this slanted line and the normal curve. After summing the net counts per minute, the concentrations in picocuries of each nuclide were determined by use of the following formula:

$$\text{pc}=\frac{\text{net counts per minute x 100}}{\text{2.2 x counting efficiency in percent x gamma abundance}}$$

Shown below are the factors by which the net counts per minute in each peak are multiplied to arrive at an estimation of the concentration of each nuclide in picocuries for planchet samples.

Multiply by factors below to convert from cpm to pc:

Source	Ru^{106}	Cs^{137}	Co^{60}
Planchet	23. 2	4. 12	4. 13

Discussion of Results

WATER

The river flow and KAPL effluent flow for the periods covered by this survey are shown in table 1–8. Column 1 shows the dates of record; columns 2 and 3, the river flows in cubic feet per second and million gallons per day, respectively; column 4, the KAPL effluent flow in million gallons per day; and column 5, the calculated dilution factors based upon the river flow and effluent flow. The average dilution factor during the period of study was about 3,000.

Figures 1–4 and 1–5 are gamma spectra of the daily KAPL effluent samples. These spectra show that the discharge from KAPL is quite variable, both in number of radioisotopes and in their relative abundance. The highest release of radioisotopes during the period of collection occurred September 25 and 26; prominent peaks indicative of zirconium-95-niobium-95, ruthenium-106, and cobalt-60 are evident

Table 1–8. Hydrologic Data on Mohawk River, September 22—October 2, 1959

Date	River flow cfs	River flow mgd	Effluent flow mgd	Dilution factor
22	1, 060	685. 0	0. 291	2, 354
23	1, 060	685. 0	0. 254	2, 697
24	871	562. 9	0. 313	1, 798
25	831	537. 1		
26	435	281. 1	0. 673	1, 292
27	79	51. 1		
28	993	641. 7	0. 280	2, 292
29	864	558. 4	0. 299	1, 868
30	1, 400	904. 8	0. 269	3, 364
1	1, 860	1, 202. 1	0. 180	6, 678
2	2, 330	1, 505. 8		
		7, 615. 0	2. 559	
			Average:	2,976

from the spectra. This sample was collected directly from the outfall line to get an actual measure of the quantities and types of radionuclides discharged into the river.

Tables 1–9 and 1–10 show concentrations of various nuclides in water and KAPL effluent. Strontium-90 values determined by radiochemical analysis are shown in the last column of table 1–9.

Table 1–9. Radionuclide Concentrations in Mohawk River and KAPL Effluent

[Activities in pc/l]

Station	$Ce^{144}-Pr^{144}$	$Ru^{106}-Rh^{106}$	$Cs^{137}-Ba^{137m}$	$Zr^{95}-Nb^{95}$	Co^{60}	Bi^{214} [a]	Ac^{228} [b]	Sr^{90} [c]
1	[d] —	—	20	[e] T	T	—	—	0. 4
2	1, 000	200	200	200	80	—	—	10, 000
3	—	—	0. 03	T	T	—	—	4. 5
4	—	—	T	T	T	—	—	
5	—	—	T	T	T	—	—	2. 2
6	—	—	T	T	T	—	—	
7	—	—	T	T	T	—	—	1. 1

[a] Member of uranium-238 series.

[b] Member of thorium-232 series.

[c] Values shown only for samples analyzed. Values obtained by radiochemical analyses.

[d] Values below limit of detectability.

[e] T indicates trace.

Table 1–10. Radionuclide Concentrations in KAPL Effluent, September 22—October 2, 1959

[Activities in pc/l]

Date of collection	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}
22–23	[a] T	[b] —	40	20	20
23–24	T	—	90	70	40
24–25	T	—	60	90	20
25–26	T	500	110	600	170
26–27	T	—	60	20	50
27–28	T	—	60	40	30
28–29	T	—	30	10	T
29–30	T	—	110	120	60
30–1	T	—	120	T	20
1–2	T	300	60	160	60

[a] T indicates trace.

[b] Values below limit of detectability.

BOTTOM SEDIMENTS

Table 1–11 shows nuclide concentrations in bottom-mud samples collected at each station. The spectra of samples collected at stations 1 and 6, which are not influenced by discharges from KAPL, show levels of fallout material considered background for the other sample locations. The spectrum of the sample collected at station 2, immediately below the KAPL outfall, shows high levels of cerium-144, cesium-137, and zirconium-95-niobium-95, with little indication of ruthenium activity. Samples collected from stations 3, 4, 5, and 7, which are influenced by KAPL discharges, show significant levels of

Table 1–11. Radionuclide Concentrations in Bottom-Mud Samples from Mohawk River

[Activities in pc/kg wet weight]

Station	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}	Sr^{90} [a]
1	300.3	[b] —	—	—	100	—	—	40	53
2	106.1	52,000	—	73,000	1,800	700	—	30	
3	249.5	—	—	2,000	—	—	—	30	300
4	219.0	—	—	1,100	300	—	—	20	
5	234.4	—	—	1,300	800	—	—	20	
6	144.4	—	—	—	400	—	—	20	
7	207.2	—	—	1,800	400	—	—	20	153

[a] Values are shown only for those stations for which samples were analyzed. Values obtained by radiochemical analyses.

[b] Values below limit of detectability.

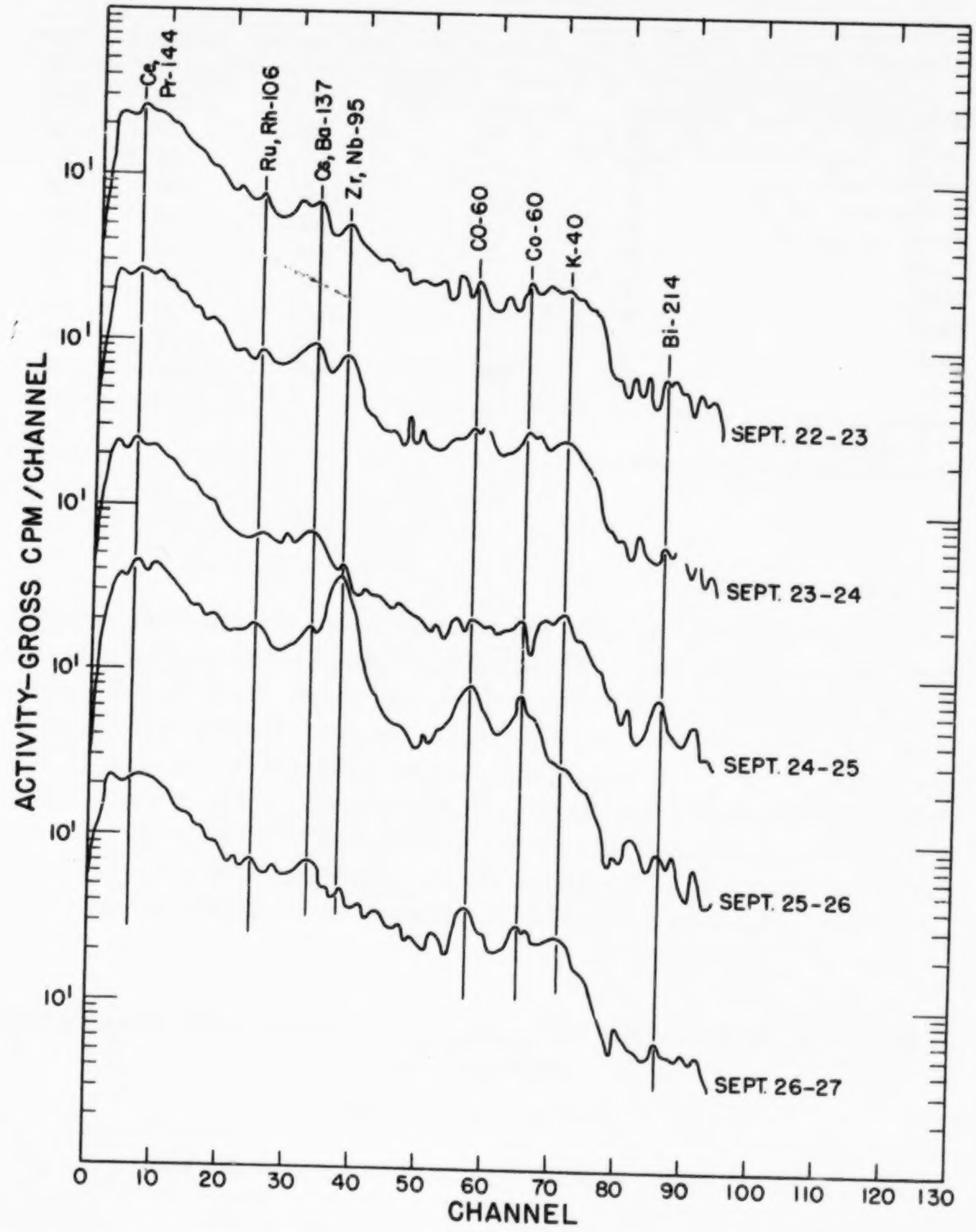

Figure 1–4. Gamma Spectra of Daily Effluent Samples, KAPL, Mohawk River (0.19 Mev.), September 22–27, 1959

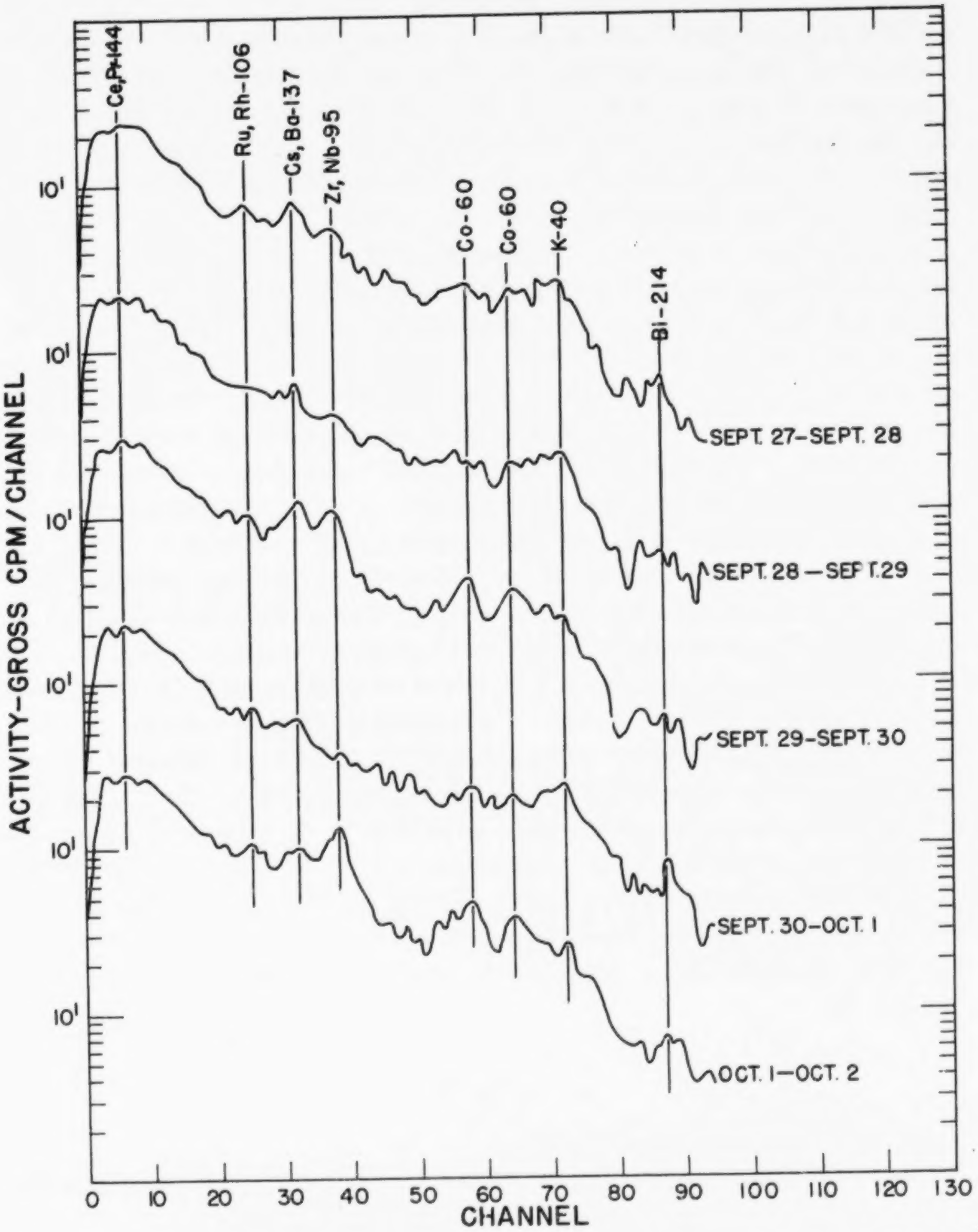

Figure 1–5. Gamma Spectra of Daily Effluent Samples, KAPL, Mohawk River (0.19 Mev.), September 27–October 2, 1959

cesium. The lack of similar peaks at stations 1 and 6 indicates that the cesium found in the bottom muds originated from the KAPL discharges. The same may be said for zirconium. It is also noteworthy that cesium levels in the shale samples collected from station 3 are about the same as those found in the mud samples collected at stations 4, 5, and 7. This may indicate that the cesium ion is able to migrate into the crystal lattice structure of this shale, while the absence of a definite zirconium peak indicates that it does not migrate appreciably into the crystal lattice structure.

The presence of a relatively higher peak of zirconium at station 5 than at stations 4 and 6 may be due to a difference in soil types, but more probably to hydraulic characteristics of the stream. The sample at station 5 was collected immediately below the power station on Crescent Dam; silts in this area would probably be better protected from scour by spring floods than would those at stations 4 and 7, which are open reaches of the river and subjected to scour at high flows. The sample at station 5, therefore, probably represents bottom muds that had been in place longer than those at stations 4 and 7.

To determine the amounts of naturally occurring activity that might be associated with these bottom muds, 200-gram samples of bottom mud from stations 1 and 5 were gamma-scanned over the range of 0 to 3.9 Mev. to quantitate the peaks of thallium-208 at 2.62 Mev. and of bismuth-214 at 1.76 Mev. The first nuclide is a decay product of thorium-232; the latter, of uranium-238. Both are present in the mud, indicating natural activity. In these spectra, other peaks of naturally occurring isotopes may be found, such as lead-214 at 0.34 Mev. and another peak of bismuth-214 at 1.12 Mev., both decay products of uranium-238. Other decay products of thorium-232 are found, principally actinium-228 at 0.90 Mev. and lead-212. Nuclide concentrations calculated from the spectra are listed in table 1–12.

Table 1–12. Radionuclide Concentrations Found in Bottom-Mud Sample from Stations 1 and 5, Mohawk River

[Activities in pc/kg wet weight]

Station	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}
1	200	[a] —	[b] T	100	10	—	120	10
5	200	—	T	20	10	—	130	10

[a] Values below limit of detectability.

[b] T indicates trace.

To determine the vertical distribution of radionuclides in the bottom sediments, a core sample was taken from the bottom of Niskayuna Pool, about 50 feet above Vischer Ferry Dam. The sample was three-quarters of an inch in diameter and was taken from the surface of the river bottom to a depth of 24 inches. Four 6-inch sections were counted individually on the 200-channel gamma spectrometer over an energy range of 0 to 3.9 Mev. Nuclide concentrations calculated from the spectra are given in table 1–13.

Table 1–13. Radionuclide Concentrations in Core Sample (Mud) from Station 2, Mohawk River

[Activities in pc/kg wet weight]

Section (inches)	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}
0–6	90.1	[a] T	T	1,400	[b] —	—	1,200	20
6–12	86.8	T	T	600	—	—	1,000	30
12–18	48.3	T	T	1,000	—	—	1,600	40
18–24	28.1	T	T	700	—	—	2,500	70

[a] T indicates trace.

[b] Values below limit of detectability.

AQUATIC BIOTA

Filamentous Algae

Gamma spectra of filamentous algae samples collected at stations 1, 2, 3, 4, and 5 were obtained. Corresponding nuclide concentrations calculated from these spectra, as well as some strontium-90 determinations, are shown in table 1–14.

Table 1–14. Radionuclide Concentrations in Filamentous Algae from Mohawk River

[Activities in pc/kg wet weight]

Station	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{210}	Ac^{228}	Sr^{90} [a]
1	150.7	800	[b] —	—	600	—	—	—	7
2	101.3	74,000	—	800	500	—	—	—	
3	60.2	—	—	200	200	—	—	—	64
4	29.8	—	—	70	1,500	—	—	—	
5	104.9	4,600	—	40	400	—	—	—	

[a] Values are shown only for those stations for which samples were analyzed. Values obtained by radio chemical analyses.

[b] Values below limit of detectability.

It is apparent from these spectra that the algae are capable of concentrating cerium-144, cesium-137, and zirconium-95-niobium-95, since the activity levels in these samples were higher on a per-gram basis than the water from which they were collected. It is probable that the concentration of these nuclides was more a result of sorption onto silt particles than incorporation into the algal cells themselves. The absence of a cesium peak at station 1 and its presence in the other samples at stations 2, 3, 4, and 5 can be taken to reflect the discharge practices at KAPL, since the effluent contained this radionuclide. The high concentration of cerium-144 in the samples collected at station 2 should be noted. Hence, the filamentous algae might serve as a useful indicator for the presence of these radionuclides in water.

Vascular Plants

Nuclide concentrations of vascular plant samples collected at stations 3, 4, and 6 are shown in table 1–15. The pondweed (*Potamogeton crispus*) at station 3 show some evidence of zirconium-95-niobium-95, and possibly of cerium-144, indicating that this plant may concentrate these radionuclides to a slight extent. The water chestnuts (*Trapa natans*) from station 4 show little, if any, tendency to concentrate radionuclides; the spectrum indicates approximately background levels in all channels. The samples from station 6 (*Nymphoides peltatum*) show only slight peaks at the cerium-144, bismuth-214, and zirconium-95-niobium-95 energy levels.

Table 1–15. Radionuclide Concentrations in Vascular Plants from Stations 3, 4, and 6, Mohawk River

[Activities in pc/kg wet weight]

Station	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}
3	109.0	26,000	[a]—	—	250	—	—	10
4	99.7	3,600	—	—	—	—	—	5
6	249.9	7,900	—	—	50	—	—	3

[a] Values below limit of detectability.

Plankton

Spectra of plankton samples all show background levels of activity.

Fish

Bluntnose minnows were collected at stations 1, 2, and 3, and young alewives were collected at stations 1, 3, and 5. Nuclide concentrations calculated from their spectra are shown in table 1–16. It will

Table 1–16. Radionuclide Concentrations in Bluntnose Minnows and Alewives from Stations 1, 2, and 3, Mohawk River

[Activities in pc/kg wet weight]

Number sampled	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}
			Bluntnose Minnows					
1	559.6	[a] —	—	—	70	—	—	—
2	823.0	—	—	10	40	—	—	—
3	710.1	—	—	10	20	—	—	—
			Alewives					
1	268	—	—	—	—	—	—	—
3	433.1	—	—	70	—	—	—	—
5	507.9	—	—	—	—	—	—	—

[a] Values below limit of detectability.

be noted that the samples collected at station 1 are at general background levels, with the bluntnose minnows, however, showing slight zirconium-95-niobium-95 concentrations. Spectra of the bluntnose minnows from station 2 show peaks at the energy level corresponding to cesium-137 and zirconium-95-niobium-95, while those from station 3 show relatively lower values for these same nuclides. The alewives collected downstream at stations 3 and 5 show little activity, with a small peak of cesium-137 in the station 3 sample. The difference in spectra is probably due to the age of the fish. Bluntnose minnows have a life span of about 3 to 4 years. Some of the fish may be assumed to have reached this age and, consequently, to have had an appreciable length of time in which to concentrate the nuclides of cesium, zirconium, and niobium. Adult alewives, however, migrate from the ocean into fresh-water streams for spawning in the spring. Consequently, juvenile alewives had probably been exposed to the river water for only 4 to 5 months, and thus the nuclide concentration is less in these fish.

Gamma spectra of large, whole, white suckers from stations 1, 3, and 4 were obtained. The high cesium-137 concentrations in the fish at station 1 may reflect the cesium concentrations in the silt, which had found its way into the stomach and intestinal tract along with food, since these fish are filter feeders. The cesium that appears in the fish at station 3 probably represents cesium in the flesh, since the river bottom where these fish were netted consists of pea-size shale with little silt. At station 4, the cesium indicated may be accounted for by the two explanations above. The ruthenium-106 in the sample collected at station 3 probably represents ruthenium that has been metabolized by the fish, since little ruthenium-106 is found in the bottom mud.

Corresponding activity levels calculated from the spectra are shown in table 1–17.

The minnow seine catches contained numerous species of small fish that, when separated by species, provided samples too small for gamma analysis. The samples were processed into two representative categories, filter feeders and sight feeders. The filter feeders were represented in collections at stations 1, 2, 3, 4, and 5. Corresponding values for nuclide concentrations calculated from their spectra are shown in table 1–18. The spectrum of the sample at station 1 shows background activity; slight peaks occur, however, in the samples collected at stations 2, 3, 4, and 5, the highest activity being indicated by the composite at station 4. Most of the filter-feeding fish were bottom feeders, and relatively high activity levels at station 4 may be due to this fact. The fish taken at station 2 were collected in a cove along the northern bank, approximately 1 mile above the powerhouse dam. In the fall of the year, it might be expected that little mixing of the KAPL effluent with the river water would occur in these reaches and, consequently, that the fish would be exposed to low levels of activity approximately equal to those at station 1. The river water and KAPL effluent become thoroughly mixed in passage through the water turbines at station 3 because of the rapid velocity in this area; little sedimentation occurs until the area around station 4 is reached. Consequently, the bottom fish may pick up activity carried down from stations 2 and 3 and deposited.

Table 1–17. Radionuclide Concentrations in White Suckers from Stations 1, 3, and 4, Mohawk River

[Activities in pc/kg wet weight]

Station	Weight (grams)	Ce^{144}–Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}
1	1,530.6	[a] —	—	60	—	—	—	—
3	1,332.5	—	700	10	—	—	—	—
4	1,172.0	—	—	10	—	-	—	—

[a] Values below limit of detectability.

Table 1–18. Radionuclide Concentrations in Filter-Feeding Fish from Mohawk River

[Activities in pc/kg wet weight]

Station	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}
1	131.2	[a] —	—	—	20	—	—	—
2	396.8	—	—	60	10	—	—	—
3	81.7	—	—	150	40	—	—	—
4	422.1	—	5,000	50	20	—	—	—
5	225.1	—	—	200	30	—	—	—

[a] Values below limit of detectability.

Composites of sight-feeding fish taken at stations 1, 2, 3, 4, and 5 were made. Corresponding nuclide concentrations are shown in table 1–19. Since these fish feed on other fish and insects, they exist at a trophic level above the filter feeders in the food chain and may be expected to concentrate radionuclides to a lesser extent. This conclusion is borne out by the activities shown, since all are practically at background levels.

To determine the difference in uptake of nuclides, particularly cesium, by various species of fish, six samples of fish collected from the river at station 2 were gamma-scanned. Nuclide concentrations calculated from these spectra are shown in table 1–20. Cesium is concentrated by each, and goldfish are apparently more efficient than the other species.

Table 1–19. Radionuclide Concentrations in Composite of Sight-Feeding Fish from Mohawk River

[Activities in pc/kg wet weight]

Station	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}
1	40.8	[a] —	[b] T	—	T	—	—	—
2	145.9	—	T	—	—	—	—	—
3	492.6	—	T	T	—	—	—	—
4	103.5	—	T	T	T	—	—	—
5	193.4	—	T	—	—	—	—	—

[a] Values below limit of detectability.

[b] T indicates trace.

Table 1–20. Radionuclide Concentrations in Various Fish from Below KAPL Outfall

[Activities in pc/kg wet weight]

Sample	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}
Yellow perch	396.0	[a] —	—	80	—	—	—	—
Alewife	623.0	—	—	70	—	—	—	—
Goldfish (L)	2,100.0	—	—	30	—	—	—	—
Goldfish (S)	129.5	—	—	900	—	—	—	—
Brown bullhead	964.0	—	—	20	—	—	—	—
Carp	1,020.0	—	—	60	—	—	—	—

[a] Values below limit of detectability.

With some of the larger fish, attempts were made to determine the location within the body of the nuclides taken from the river. Consequently, one large carp at station 2, two large carp at station 3, and eight yellow perch from station 5 were separated into six component samples and each sample processed separately. The components were flesh, bone, liver, intestines and intestinal contents, remaining viscera, and scales. Nuclide concentrations for these samples are shown in table 1–21. In the two carp samples from stations 2 and 3, cesium shows up mostly in the intestines and contents, with lesser amounts in the flesh. Ruthenium appears in the bone. The naturally occurring radionuclides, which are heavy metals and bone seekers, are found in the bone as well as in the intestinal content. In the yellow perch specimens taken from station 5, cesium appears to be relatively abundant in the bones, scales, and intestines. Cesium appears predominantly in the flesh and bone, with lesser amounts in the intestines (as compared with the carp), and probably reflects the piscivorous nature of this fish.

Table 1–21. Radionuclide Concentrations in Components of Fish from Mohawk River, September—October 1959

[Activities in pc/kg wet weight]

Sample	Weight (grams)	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}	Bi^{214}	Ac^{228}	Sr^{90} [a]
			Carp—Station 2						
Flesh	1,390.3	[b] —	—	30	—	—	5	—	14
Bone	424.5	—	—	—	—	—	—	—	238
Liver	31.7	—	—	—	—	—	—	—	
Intestine and contents	71.5	—	[c] T	400	—	—	—	—	
Viscera	694.1	—	—	30	—	—	—	—	
Scales	301.0	—	—	—	—	—	—	—	
			Carp—Station 3						
Flesh	2,067	—	—	30	—	—	—	—	27.6
Bone	651	—	—	—	—	—	—	4	230
Liver	42.6	—	—	—	—	—	—	—	
Intestine and contents	105	—	—	5,000	100	—	—	60	
Viscera	182.6	—	—	—	200	—	—	—	
Scales	234.5	—	—	—	T	—	—	—	
			Yellow Perch—Station 5						
Flesh	804.1	—	—	80	—	—	—	—	
Bone	128.6	—	—	1,100	—	—	—	—	
Liver	25.8	—	—	—	—	—	—	—	
Intestine	25.5	—	—	200	200	—	—	—	
Viscera	132.0	—	—	70	60	—	—	—	
Scales	47.9	—	—	40	30	—	—	—	

[a] Sr^{90} values shown only for samples analyzed. Values obtained by radiochemical analyses.

[b] Values below limit of detectability.

[c] T indicates trace.

ARTIFICIAL MEDIA

The artificial media samples were returned to the laboratory and gamma-scanned. Accumulated nuclide concentrations calculated from these spectra are shown in table 1–22. The concentration factors for each radionuclide, calculated from the abundance of the nuclides in the artificial media samples and divided by that in the composite effluent sample (table 1–9), are shown in table 1–23.

The spinach sample at station 1 shows definite peaks at the energy level of cerium-144 and ruthenium-106. Little else could be identified. At station 2, where the spinach was placed directly in the KAPL effluent, the nuclides cerium-144, cesium-137, zirconium-95-niobium-95 and cobalt-60 are identifiable. Spectra of samples placed at station 4 show only slight traces of zirconium-95-niobium-95 and cobalt-60; the other nuclide concentrations shown in the spectra at station 2 have dropped to background levels.

The tea sample at station 1 shows levels one might expect from fallout. The tea placed in the KAPL effluent shows definite peaks at energy levels of cerium-144, ruthenium-106, cesium-137, cobalt-60, and the highest peaks for zirconium-95-niobium-95. The spectrum found in the tea samples placed at station 4 is similar to that obtained at station 2, but the peaks are lower.

Nuclide concentrations calculated from the spectra of *Pithophora* samples placed at station 1 show the presence of cesium-137 and zirconium-95-niobium-95; those at station 2 show cerium-144, ruthenium-106, cesium-137, zirconium-95-niobium-95, and cobalt-60. Similar peaks are observed in the tea and spinach samples placed at the same location. The composite algae spectrum (excluding sample from station 2) shows cesium-137 and zirconium-95-niobium-95. Live algae are reported to be good concentrators of cesium from a water medium. This is confirmed by the algal spectrum at station 1 and the composite sample that shows a better defined peak at the cesium energy level than that observed with the tea or spinach samples.

Table 1–22. Radionuclide Concentrations in Artificial Media

[Activites in pc/kg]

Media	Station	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}
Spinach bags	1	[a] —	—	—	[b] T	—
	2 (Effluent)	56, 000	—	685	685	410
	4	—	—	—	T	T
Tea bags	1	—	—	—	—	—
	2 (Effluent)	9, 100	6, 500	282	630	110
	4	2, 650	1, 900	T	T	T
Algae bags	1	—	—	210	T	—
	2 (Effluent)	150, 000	86, 000	3, 000	11, 500	1, 300
	Composite	—	—	200	T	T

[a] Values below limit of detectability.

[b] T indicates trace.

Table 1–23. Radionuclide Concentration Factors in Artificial Media

Media	Station	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Co^{60}
Spinach bags	1	[a] —	—	—	—	—
	2 (Effluent)	56.0	—	3.4	3.4	5.1
	4	—	—	—	—	—
Tea bags	1	—	—	—	—	—
	2 (Effluent)	9.1	32.5	1.4	3.2	1.4
	4	([b])	([b])	—	—	—
Algae bags	1	—	—	1.1	—	—
	2 (Effluent)	150	428	15.0	57.5	16.3
	Composite	—	—	([b])	—	—

[a] Values below limit of detectability.

[b] Not obtainable. Lack of water data.

A greater concentration of zirconium-95-niobium-95 than of cesium-137 was taken up by the algae at station 2. A possible explanation of this is that, although the algae were alive when placed in the effluent stream, the chlorine which had been added to the waste killed them rapidly. The uptake, then, from the KAPL effluent was probably that of dead algae, and this may explain why the algae at station 2 took up more zirconium-95-niobium-95 than cesium-137, while the reverse was true of the composite samples.

Nuclide concentrations calculated from the gamma spectra of the cation resin columns after treatment with KAPL effluent and the Mohawk River water are shown in table 1–24. The spectrum of the resin columns treated with river water shows background nuclide levels with little indication of the nuclides present in the KAPL effluent. From this, the conclusion must be drawn that resin columns used in this test are not efficient concentrators of nuclides and, consequently, would serve as poor monitoring tools.

Table 1–24. Radionuclide Concentrations in Mohawk River Water and KAPL Effluent Passed Through Ion-Exchange Columns

Station	ml	Ce^{144}–Pr^{144}	Ru^{106}–Rh^{106}	Cs^{137}–Ba^{137m}	Zr^{95}–Nb^{95}	Co^{60}	K^{40}	Bi^{214}	Ac^{228}
1	2,000	[a] —	—	—	—	—	—	—	—
2	2,000	—	—	100	30	20	—	—	—
3	2,000	—	—	—	—	—	—	—	—
4	2,000	—	—	—	—	—	—	—	—
5	2,000	—	—	—	—	—	—	—	—
6	2,000	—	—	—	—	—	—	—	—
7	2,000	—	—	—	—	—	—	—	—

[a] Values below limit of detectability.

Summary and Conclusions

From the results of analyses of water samples collected from the Mohawk River, it would appear that the choice of water samples of nominal size for monitoring purposes would furnish the poorest results of any of the media tested. As a basic control measure, however, for the protection of the water user and consumer affected by the waste disposal practice of atomic energy installations and nuclide users, the activity in the water must be measured.

Strontium-90 levels in water from Vischer Ferry Dam to the last sampling station on the Hudson River are shown in figure 1–6. Strontium appears to be taken out of the water quite slowly and it is possible that, if corrections were made for dilution by the Hudson River at station 7, a straight-line variation might be obtained.

Bottom mud appears to be the best medium for concentration of cesium and zirconium in the area of the river sampled. This may not be true at all locations, however, since uptake is probably dependent on the quality of the water. The results of this survey point out that the location selected for sampling bottom mud must be chosen with care, and the physical characteristics of the stream in the area where data are desired must be considered.

Figure 1–7 is a plot of activity in bottom muds for the various stations along the Mohawk River. Each of the three nuclides (cesium-137, zirconium-95, and strontium-90) shows a high value at station 2, with a rapid dropoff to station 3, and fairly uniform activities on down the stream. Values downstream are lower by a factor of 10 to 100 than the maximum values observed at station 2.

Figure 1–8 shows distribution of nuclides in filamentous algae collected along the river. Conspicuous are extreme variations and high values for cerium-144. The variations may possibly be accounted for by taking into account the type of water from which these algae were collected. Unfortunately, filamentous algae were rather scarce and samples were collected, not on the basis of the most desirable location, but on the basis of where they could be found. The cesium appears to decrease in the algae, as in the bottom muds. Zirconium, on the other hand, appears in about equal concentrations at all stations along the river, and indicates possible contamination from fallout.

From this survey, it does not appear that vascular plants will serve as monitoring media. Since the samples from stations 4 and 6 were collected from stagnant water and showed only background activity (while that from station 3, which was collected from moving water, showed higher activity levels), the poor uptakes indicated may have been the result of a poor choice of sampling location.

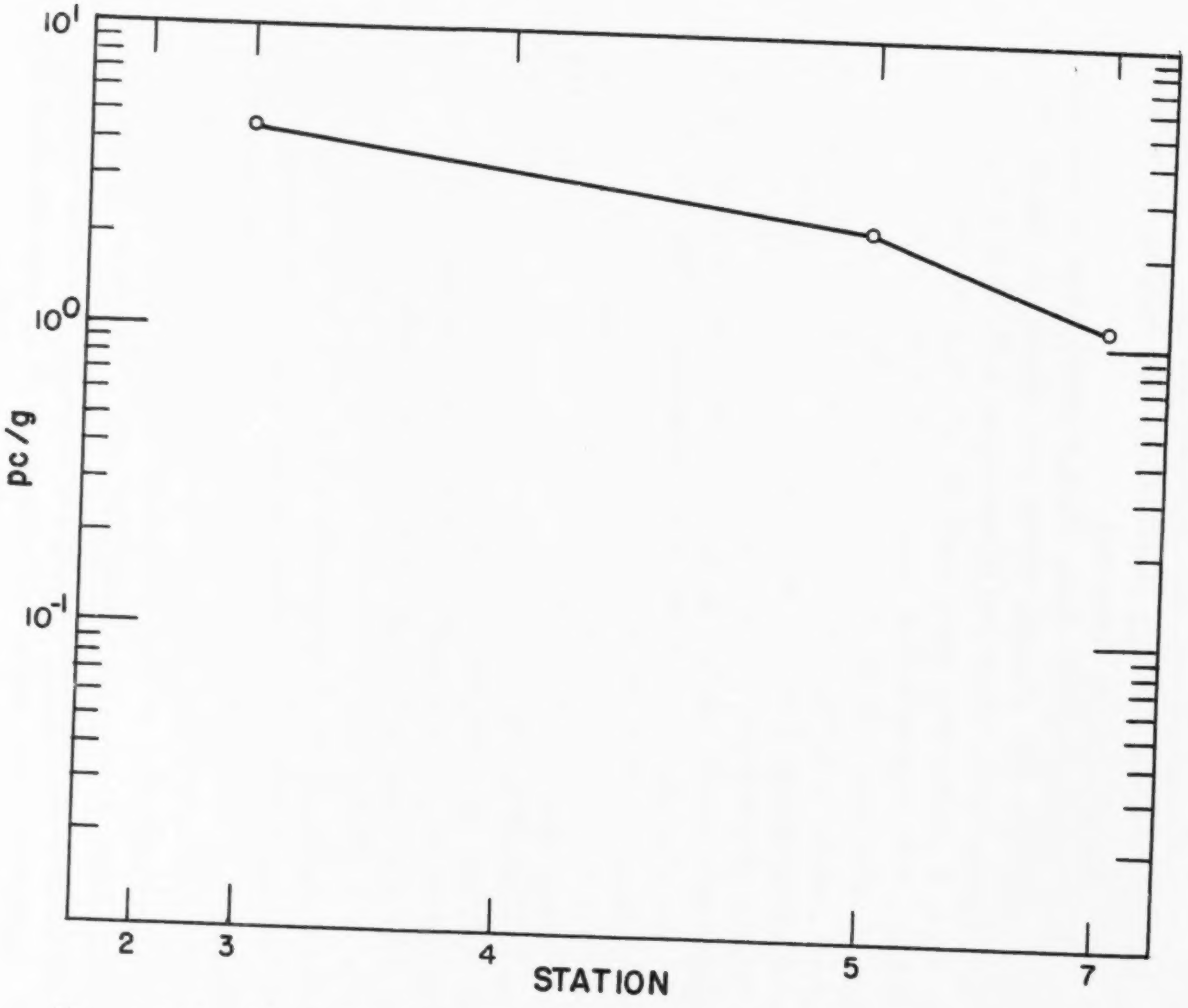

Figure 1–6. Variation of Sr^{90} Activities in Water at Various Stations Along the Mohawk River

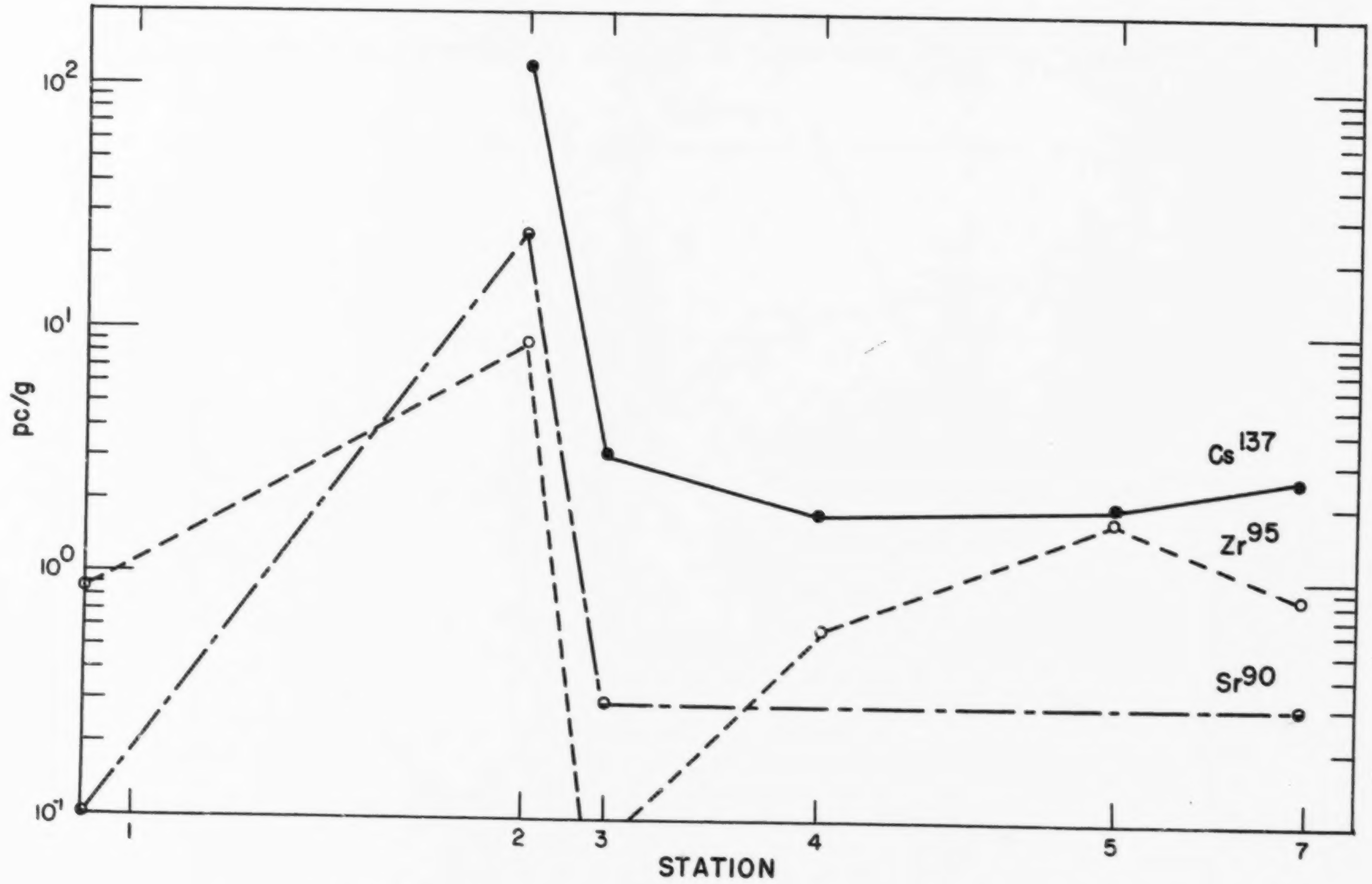

Figure 1–7. Variations in Activities in Bottom Muds at Different Stations Along the Mohawk River

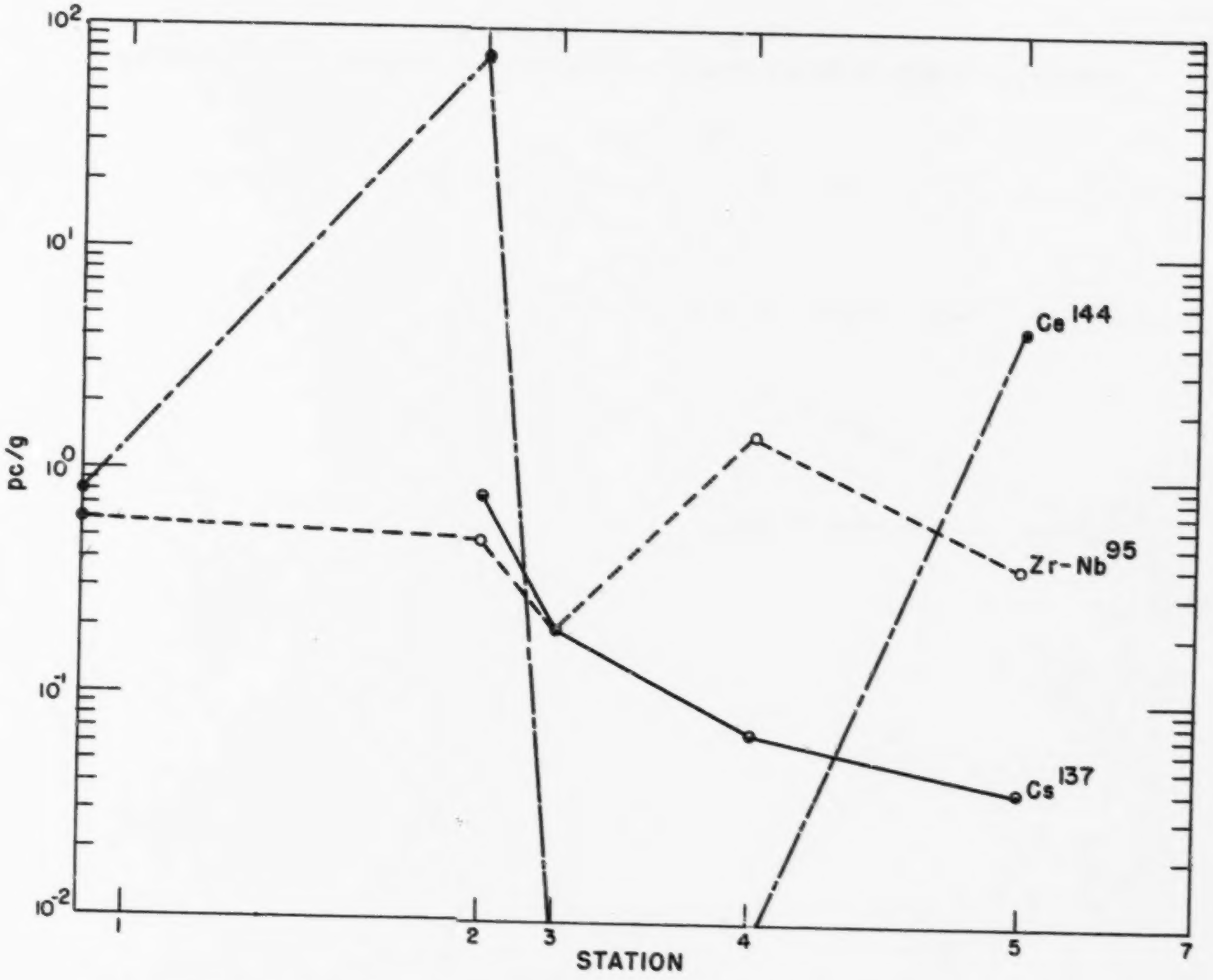

Figure 1--8. Variation in Activities in Filamentous Algae at Different Stations Along the Mohawk River

Little information can be obtained from this study on the suitability of plankton as a monitoring device because of the small size of the samples collected.

The nuclide concentrations found in fish on a per-gram basis are low. Since fish do, however, concentrate activity to a small degree, they are better for monitoring than the water itself. In general, it is often found that fish low on the food chain are better concentrators of nuclides than those at a higher trophic level. In other words, for monitoring purposes it would be better to sample species such as carp, suckers, and catfish than it would be to sample game species such as bass and yellow perch. Again, however, for public health purposes (since the latter fish are consumed as food), it will be necessary to sample these species to assess properly the hazards associated with radionuclide discharge practices.

Of the biological media tested, fish appear to be the best media for concentration of ruthenium.

Figure 1–9 shows distribution of activity in the bottom- or filter-feeding fishes. The only nuclides appearing throughout the length of the river are cesium-137 and zirconium-95. These activities correspond in general to activities in the bottom muds.

Of the artificial media tested, tea and algae appear to be most satisfactory for monitoring. Tea samples provided a better spectrum of nuclide concentrations than did the algae samples. The behavior of the algae showed different specificities for nuclides. At station 2, where the algae were dead, they concentrated zirconium-95-niobium-95 more than cesium, while the live algae at station 4 gave reversed results.

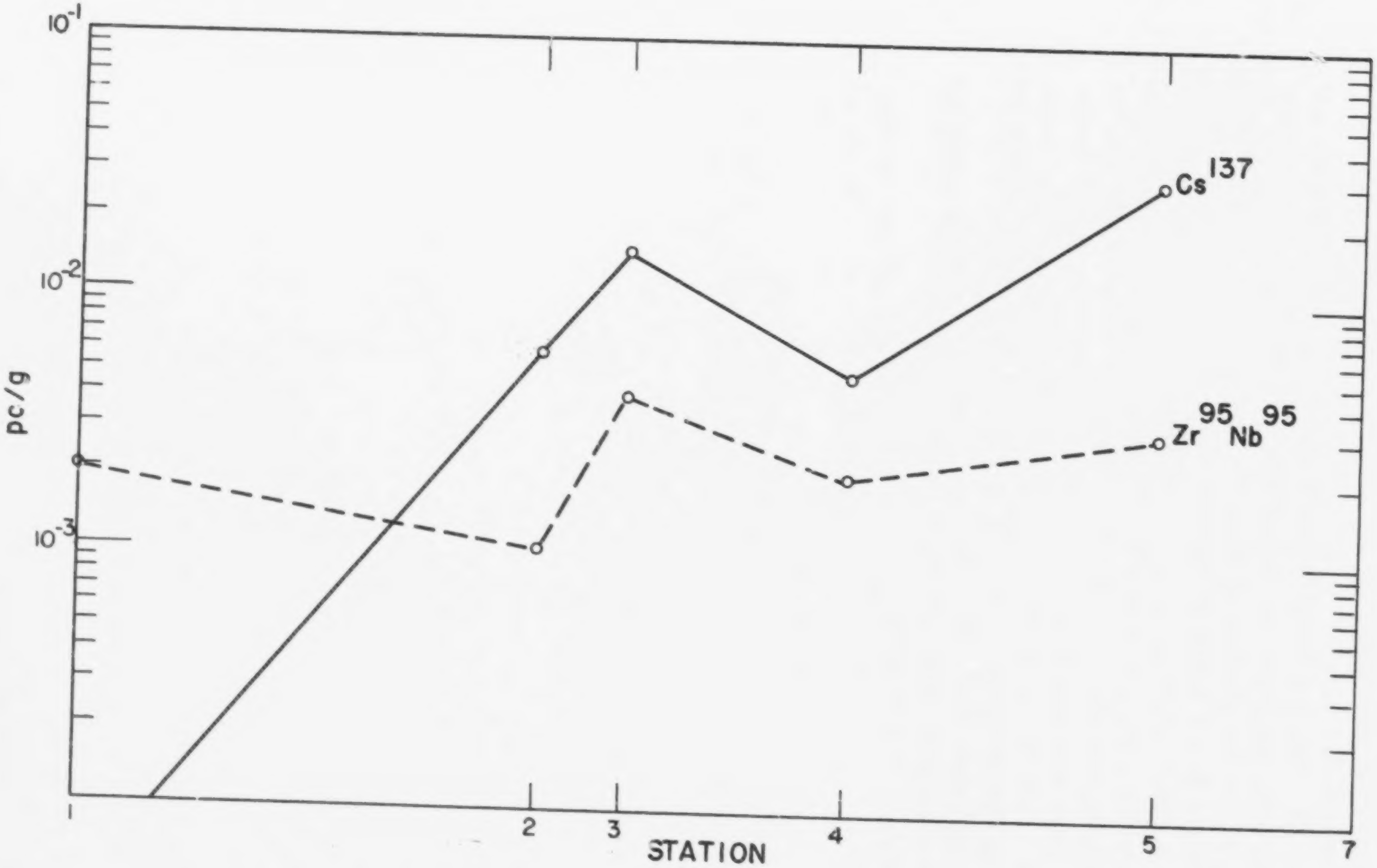

Figure 1–9. Variation in Activities in Bottom- or Filter-Feeding Fish at Different Stations Along the Mohawk River

SECTION II: CLINCH RIVER STUDY—FEBRUARY 1960

Introduction to Study Area

A description of the biological conditions in the study area (fig. 2–1), Norris Lake to Chattanooga, is difficult because of its variable nature. In general, it consists of impounded water, with the exception of a 50- to 60-mile stretch of fast, clear, cold Clinch River water extending from Norris Dam to the pool area formed by Watts Bar Dam (usually about 8 miles downstream from the mouth of White Oak Creek). This 50-mile stretch contains different biota from the remainder of the area, and as a result a fair amount of rainbow trout sport fishing has developed.

Generally, mixed populations of warm-water game, forage, and rough species of fish are found in downstream waters of the Tennessee Valley Authority system. Norris Reservoir differs from the other reservoirs sampled (Watts Bar and Chickamauga) in that it has a greater depth, a sharply declining shoreline, and cleaner, colder waters. Norris Lake is noted for its walleye and smallmouth bass sport fishing, whereas downstream waters support crappies, bluegills, and largemouth bass; tailwaters of the Watts Bar and Chickamauga Dams sometimes furnish excellent fishing for such reservoir species as saugers and white bass, as well as for large catfish. Commercial fishing is extensive and the major species caught (by trammel nets, 3- to 5-inch mesh) are paddlefish, carp, carpsuckers, redhorse suckers, and catfish. At the time of the study, commercial fishing was being conducted in Norris Lake and from Kingston downstream; sport fishing, mainly for saugers and white bass, was concentrated in the tailwaters of Watts Bar and Chickamauga Dams. The whole area is widely used by sport and commercial fishermen and also for general water-recreation activities.

Flows in the area are closely controlled by the operation of flood-control dams by the Tennessee Valley Authority. The first impoundment below the point of waste discharge is by Watts Bar Dam at TRM 529.9. The pool area formed by Watts Bar Dam may extend upstream in the Clinch River to the mouth of White Oak Creek (CRM 20.8), but during the period of this study the pool area began at about CRM 14.

Table 2–1 shows average discharges from Norris Dam (CRM 79.8), Fort Loudoun Dam (TRM 602.3), Watts Bar Dam (TRM 529.9), Chickamauga Dam (TRM 129.9), and Chilhowee Dam on Little Tennessee River (LTRM 33.6). The Little Tennessee River empties into the Tennessee River at about TRM 601.0, 1.3 miles below Fort Loudoun Dam. The discharges from Norris Dam to the Clinch River arm of Watts Bar Reservoir furnish the major portion of the dilution water for White Oak Creek wastes; the Emory River, which flows into the Clinch at CRM 4.1, contributes a small amount. A further dilution of the wastes occurs, after the Clinch River enters the Tennessee River at TRM 567.6, by discharges from the Fort Loudoun and the Chilhowee Dams.

The flow of White Oak Creek could not be determined because the gaging station at White Oak Creek Dam was not functioning during the study period, and actual dilution factors could not be calculated. Subsequent data, however, show dilutions by the Clinch River water in an average ratio of between 250 and 500 to 1, with further dilutions by the Tennessee River averaging between 5 and 6 to 1.

Precipitation for the first half of February is shown in table 2–2.

Table 2–1. Average Daily Discharges on the Clinch, Tennessee, and Little Tennessee Rivers, February 1–15, 1960

[Average daily discharge in cfs]

Day	Watts Bar Dam	Chickamauga Dam	Fort Loudoun Dam	Norris Dam	Chilhowee Dam
1	19, 100	25, 700	8, 000	354	4, 620
2	13, 200	21, 700	4, 200	1, 730	4, 589
3	21, 600	30, 100	9, 400	1, 697	4, 712
4	20, 500	31, 400	13, 400	2, 230	4, 171
5	28, 200	33, 000	13, 500	0	3, 846
6	22, 000	27, 900	11, 600	2, 190	3, 726
7	28, 200	36, 400	15, 200	1, 542	2, 267
8	27, 700	36, 800	14, 100	5, 240	3, 491
9	30, 300	37, 400	13, 500	4, 567	2, 612
10	31, 000	36, 800	16, 400	3, 154	3, 013
11	28, 300	37, 700	16, 400	2, 372	4, 437
12	33, 800	41, 600	17, 400	1, 840	4, 438
13	29, 900	39, 800	18, 500	2, 672	4, 178
14	29, 200	38, 400	16, 100	0	2, 487
15	34, 300	39, 600	15, 800	5, 011	3, 651
Avg.	26, 500	34, 300	20, 400	2, 310	3, 750

Note: Data courtesy Tennessee Valley Authority.

Table 2-2. Precipitation at Oak Ridge, February 1-15, 1960

Day	Inches
4	0.15
5	0.66
6	0.06
10	0.80
13	0.69
Total	2.36

Note: Data courtesy U.S. Weather Bureau.

Sampling Points, Collection, Preparation, and Analysis

SAMPLING POINTS AND SAMPLE COLLECTIONS

Water, bottom sediment, and biota samples were collected from seven points on the Clinch and Tennessee Rivers (fig. 2-1).

Station 1 was the area above Norris Dam (CRM 79.8). A water sample was collected at the concession stand approximately one-fourth mile north of Norris Dam; the mud sample was collected in the vicinity of the Pellissippi boat dock, approximately 6 miles above the dam on the Clinch River arm of the reservoir; and one large fish sample was collected from the mouth of the cove at the boat dock. Two other fish samples were collected from the upper reaches of Norris Lake, where commercial fishermen were active. Minnows were collected from a small feed stream about 3 miles above Norris Dam. As a part of the sampling for station 1, filamentous algae and one live clam were collected in a stretch of the river between Norris Dam and White Oak Creek, about 20 miles below Norris Dam.

The station 2 water sample was collected from White Oak Creek about 50 feet upstream from its point of entry into the Clinch River (CRM 20.8). Fish samples were collected at the mouth of White Oak Creek and at a point about 150 yards downstream from the mouth. Bottom mud samples were collected in the vicinity of the dam on White Oak Creek, at the mouth of White Oak Creek, and about 150 yards downstream in the Clinch River. A soil sample was

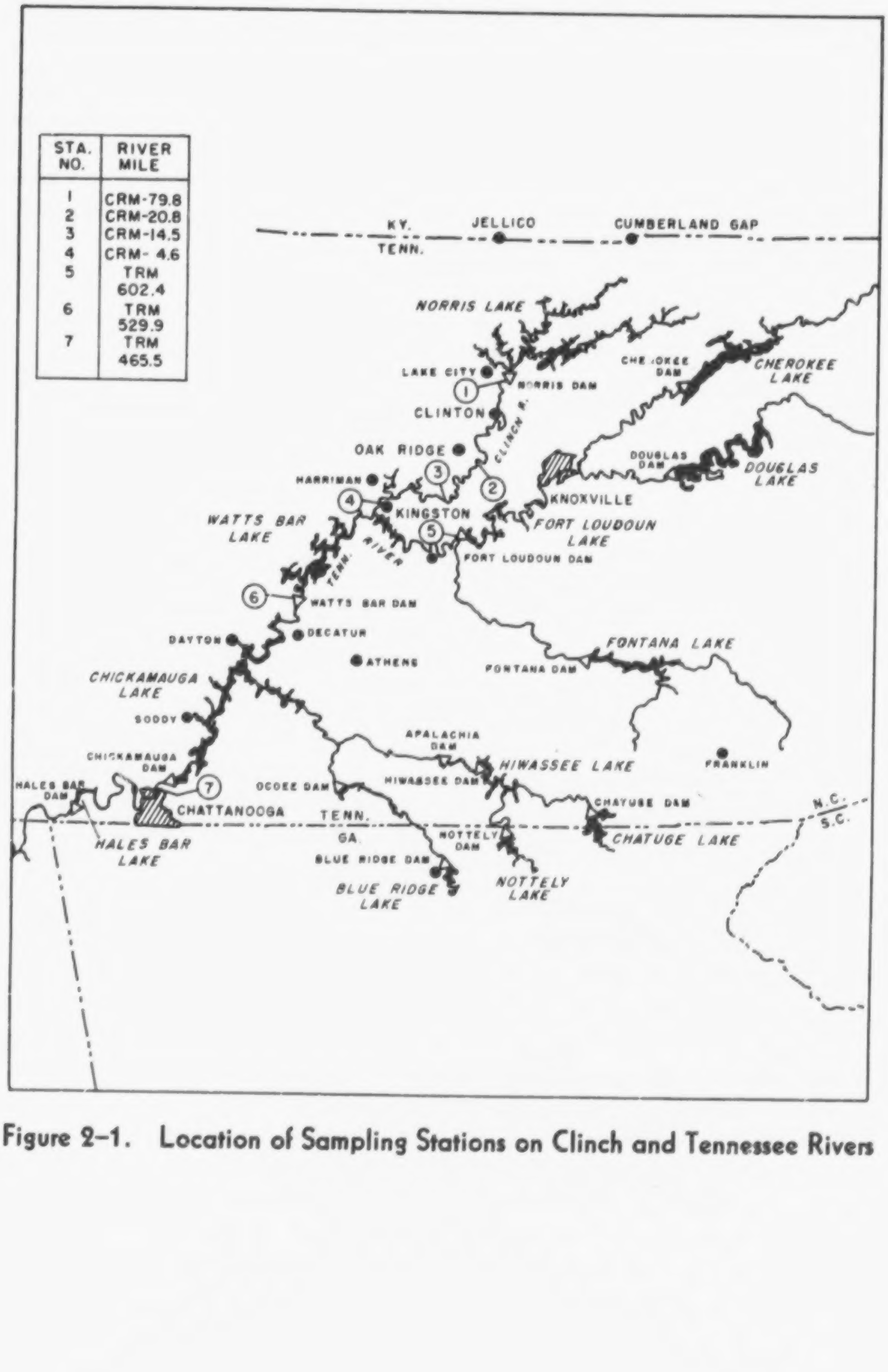
STA. NO. | RIVER MILE
1 CRM-79.8
2 CRM-20.8
3 CRM-14.5
4 CRM- 4.6
5 TRM 602.4
6 TRM 529.9
7 TRM 465.5
KY.
TENN.
JELLICO
CUMBERLAND GAP
NORRIS LAKE
LAKE CITY
NORRIS DAM
CLINTON
CLINCH R.
CHEROKEE DAM
CHEROKEE LAKE
OAK RIDGE
HARRIMAN
KINGSTON
DOUGLAS DAM
DOUGLAS LAKE
KNOXVILLE
WATTS BAR LAKE
TENN. RIVER
FORT LOUDOUN LAKE
FORT LOUDOUN DAM
WATTS BAR DAM
DAYTON
DECATUR
ATHENS
FONTANA LAKE
FONTANA DAM
CHICKAMAUGA LAKE
SODDY
APALACHIA DAM
CHICKAMAUGA DAM
HIWASSEE LAKE
FRANKLIN
HALES BAR DAM
OCOEE DAM
HIWASSEE DAM
CHATTANOOGA
TENN.
GA.
CHATUGE DAM
N.C.
S.C.
HALES BAR LAKE
NOTTELY DAM
CHATUGE LAKE
BLUE RIDGE DAM
BLUE RIDGE LAKE
NOTTELY LAKE
1
2
3
4
5
6
7

Figure 2–1. Location of Sampling Stations on Clinch and Tennessee Rivers

taken from the creek bank near the mouth of White Oak Creek. Three additional sediment samples were collected from Bear Creek on the Oak Ridge Reservation.

The water sample collected at station 3 was taken from the Clinch River at the center pier of Gallaher Bridge (CRM 14.5), near the mouth of Grassy Creek. One bottom-sediment sample was taken about 1 mile below the mouth of Poplar Creek (CRM 12.0) at buoy 10.9, and another about 200 yards below the Poplar Creek point of entry into the Clinch River. Fish samples were collected just above and just below Gallaher Bridge; also one medium-size, eastern, painted turtle, found in the gill net just below Gallaher Bridge, was used as a sample.

The water sample from station 4 was collected from the south bank of the Clinch River at Centers Ferry (CRM 4.6), almost opposite the point where the Emory River enters the Clinch. Mud samples were taken at the mouth of the Emory River and about one-fourth mile above Centers Ferry in the Clinch River. Large fish were collected about one-half mile below Highway 70 Bridge west of Kingston (CRM 2.2), and a small fish sample about one-fourth mile above Centers Ferry.

The water sample at station 5 was collected immediately above the face of the Fort Loudoun Dam (TRM 602.4); security officers at the dam changed the sample bottles daily. Mud and fish samples from Fort Loudoun Reservoir were collected at a public picnic area about 8 miles above the dam.

The station 6 water sample was collected from the tailrace below Watts Bar Dam (TRM 529.9). A mud sample and a clam shell were collected about one-half mile below the dam.

Daily water samples collected at station 7 by the plant superintendent of the Chattanooga Water Treatment Plant consisted of hourly composites of both raw intake water and treated water. The superintendent also obtained a sample of settled filter sludge approximately 8 months old, a sample of backwash water, and a sample of used filter sand from the Chattanooga Water Treatment Works. Mud samples were taken from the upstream face of the Chickamauga Dam (TRM 469.9), and from South Chickamauga Creek, about one-quarter mile upstream from its mouth and below the waste discharge of the heavy metals industries. Fish samples included four catfish from the Chickamauga Reservoir in the vicinity of TRM 477 near Hixson; a medium-sized gizzard shad from immediately below the Chickamauga Dam; and a buffalo fish at Hales Bar Dam near Shellmound, in the vicinity of TRM 425.

SAMPLE PREPARATION AND ANALYSIS

Samples analyzed are listed in table 2–3. The numbers indicate samples analyzed rather than samples collected; i.e., an individual fish may furnish from one to seven samples when separated into its component parts.

Where possible, water was sampled continuously during the entire collecting period.[2] Since no sampler was placed at station 6, that sample represents a composite of two 2-gallon grab samples. Hourly grab samples collected by the Chattanooga Water Treatment Plant personnel at station 7 were composited to make a daily 2-gallon sample. All water samples were stored and shipped without preservative in 2-gallon polyethylene bottles.

Table 2–3. Type and Quantity of Samples from Each Station

Sample type	Sampling station[a]								Type totals
	1	2	3	4	5	6	7	X	
Algae bags	----	5	----	----	----	----	----	10	15
Clam (shells)	1	----	----	----	----	1	----	----	2
Crayfish	1	----	----	----	----	----	----	----	1
Filamentous algae	1	----	----	----	----	----	----	----	1
Filter sand	----	----	----	----	----	----	2	----	2
Fish	18	6	40	38	9	----	16	----	127
Mud	1	4	4	2	1	1	2	4	19
Plankton tow	1	----	1	1	1	----	----	----	4
Rock	----	----	----	----	----	----	----	1	1
Sand wash water	----	----	----	----	----	----	3	----	3
Sludge	----	----	----	----	----	----	1	----	1
Snails	1	----	----	----	----	----	----	----	1
Spinach bags	----	5	----	----	----	----	----	6	11
Tea bags	----	11	----	----	----	----	----	13	24
Turtle	----	----	1	----	----	----	----	----	1
Water	1	6	5	1	1	1	2	----	17
Station totals	25	37	51	42	12	3	26	34	230

[a] 1—Clinch River at Norris Dam (CRM 79.8).
2—Clinch River at White Oak Creek (CRM 20.8).
3—Clinch River at Gallaher Bridge (CRM 14.5).
4—Clinch River at Centers Ferry (CRM 4.6).
5—Tennessee River at Fort Loudoun Dam (TRM 602.4).
6—Tennessee River at Watts Bar Dam (TRM 529.9).
7—Tennessee River at Chattanooga.
X—Three different locations on Bear Creek.

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[2] Collected with a DC Effluent Sampler, available from Brailsford & Company Rye, N.Y.

Daily 1-gallon water samples were composited to give a 10-gallon sample at each station. These samples were then evaporated to 3.5 liters, counted on the gamma spectrometers in 3.5-liter, well-type, milk beakers, gamma-scanned, then analyzed for strontium-90.

Bottom sediment samples were collected with an Ekman or Petersen dredge; the latter was used only where the bottom deposits contained pebbles or hard, clayey materials. After collection, they were placed in pint-sized, plastic, cottage cheese containers for storage, transportation, and subsequent gamma counting. No preservatives were added nor was special laboratory preparation given these samples. They were weighed as received and placed directly onto the detector for gamma scanning. Because of high activity in the samples from stations 2 and 3, samples of approximately 5 grams were air-dried, weighed, and counted on a stainless-steel planchet.

Separate plankton samples for numerical count and weight analysis were collected by dipping a water composite (1 gallon for count, 2 gallons for weight) from the surface as the watercourse was crossed. At the same time, a No. 20 plankton net (173 mesh) was towed to collect a sample for radionuclide analysis. The sample for count was preserved with thimerosal, the other samples with 5-percent formaldehyde solution.

Plankton counts, consisting of a direct clump count of 2 strips (instead of 10 fields) of a Sedgewick-Rafter counting cell with a magnification of 200, were made by Dr. Louis G. Williams of the Robert A. Taft Sanitary Engineering Center. This procedure is similar to that used in the Basic Water Quality Network of the Public Health Service. The counts indicated a very sparse population consisting mostly of diatoms, as shown below:

Station 1—Norris Reservoir—February 9, 1960	
Melosira (centric diatom)	11/ml
Station 4—Clinch River—Centers Ferry—February 14, 1960	
Synedra (pennate diatom)	22/ml
Station 4—Emory River—February 14, 1960	
Chlamydomonas (green flagellate)	23/ml
Ceratoneis (pennate diatoms)	23/ml
Total	46/ml
Station 5—Tennessee River—Fort Loudoun Reservoir—February 10, 1960	
Cyclotella (centric diatom)	68/ml
Synedra (pennate diatom)	91/ml
Total	159/ml

Station 7—Tennessee River at Chattanooga—February 15, 1960

Chlamydomonas (green flagellate)	46/ml
Golenkinia (coccoid green alga)	23/ml
Cryptomonas (pigmented flagellate)	46/ml
Cyclotella (centric diatom)	114/ml
Melosira (centric diatom)	68/ml
Asterionella (pennate diatom)	46/ml
Navicula (pennate diatom)	46/ml
Synedra (pennate diatom)	114/ml
Total	503/ml

Plankton weight samples (usually 5 liters) were centrifuged in a Foerst centrifuge, air-dried, ashed (600° C. for 30 minutes), and weighed. Radionuclide samples were filtered through Whatman No. 2 filter paper in a Buchner funnel, and the filtered and air-dried weights were recorded. After use, the filters containing the plankton were placed in stainless-steel planchets and gamma-scanned. Strontium-90 was not determined. Because of the sparse population, the size of samples used was not considered valid for weight determinations. The tow samples also were considered inadequate for radionuclide analysis.

Filamentous algae and bottom organisms were picked up when found and preserved in 10-percent formaldehyde solution. Except in the Clinch River above the backwater of Watts Bar Reservoir, where *Cladophora* sp. was abundant on rocks in fast water, filamentous algae and higher aquatic vegetation were extremely scarce.

No systematic attempt was made to collect bottom organisms, since this was to be carried out by Oak Ridge National Laboratory personnel. Clams were divided into shell and flesh; these were gamma-scanned and the shells were ashed and analyzed for strontium-90. The crayfish and snails were ashed whole, placed in plastic containers and scanned, and then analyzed for strontium-90.

The live turtle was placed in a small cardboard box and set directly on the crystal; no strontium-90 analysis was made.

Small fish were collected by seining with ¼-inch mesh nets in slough or shallow water areas; bottom sets with 1-, 2-, and 3-inch nylon gill nets were used for large fish, or fish were obtained from commercial fishermen in the area. Fish samples were preserved in 10-percent formaldehyde solution for transport to the laboratory. They were then identified, weighed, and separated into parts or organs for radionuclide analysis.

The principal fish collections were made in the Clinch River between the mouth of White Oak Creek and Kingston, where commercial fishing was not practiced. Shad, white bass, and saugers predominated in gill-net catches.

After the fish were separated according to species, they were divided into component parts, placed in standard plastic counting and storage containers, preserved with formaldehyde solution and counted on the gamma spectrometer. For strontium-90 analyses the samples were ashed at 600° C. in a muffle furnace. The following species of fish were collected:

Skipjack herring	*Alosa chrysochloris*
Gizzard shad	*Dorosoma cepedianum*
Carp	*Cyprinus carpio*
Spotfin shiner	*Notropis spilopterus*
Bluntnose minnow	*Pimephales notatus*
Bullhead minnow	*Pimephales vigilax*
Blacknose dace	*Rhinichthys atratulus*
River carpsucker	*Carpiodes carpio*
Quillback	*Carpiodes cyprinus*
Smallmouth buffalo	*Ictiobus bubalus*
Bigmouth buffalo	*Ictiobus cyrinellus*
Channel catfish	*Ictalurus punctatus*
White bass	*Roccus chrysops*
Bluegill	*Lepomis macrochirus*
Smallmouth bass	*Micropterus dolomieui*
Largemouth bass	*Micropterus salmoides*
Logperch	*Percina caprodes*
Sauger	*Stizostedion canadense*
Sculpin	*Cottus* sp.
Brook silverside	*Labidesthes sicculus*

Results and Discussion of Results

WATER

Radionuclide concentrations in water samples from stations on the Clinch and Tennessee Rivers are shown in table 2–4. The predominant radioisotopes are cerium-144-praseodymium-144, ruthenium-106-rhodium-106, cesium-137-barium-137m, cobalt-60, and strontium-90. Traces of zirconium-95-niobium-95 and possibly zinc-65 are indicated. The activities are plotted in figure 2–2, which shows that cerium-144-praseodymium-144 and cobalt-60 disappear from the water phase quite rapidly; little activity from either of these nuclides is noted beyond station 3. Cesium-137 also seems to disappear rapidly from the water phase, and no activity from this nuclide is indicated below station 4. This rapid reduction is due to the uptake by the bottom muds of cerium-144-praseodymium-144, cobalt-60, and cesium-137-barium-137m from the water phase by precipitation, adsorption, or ion exchange. The ruthenium and strontium, however, appear to remain in the water phase for appreciable lengths of time (and distance).

Table 2–4. Radionuclide Concentrations in Water at Various Stations on the Clinch and Tennessee Rivers, February 1960

[Activities in pc/l]

Station	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	Sr^{90}
1 (CRM 79.8)	[a] —	—	—	—	—	—	0.5
2 (CRM 20.8)	980	14,000	2,200	[b] T	—	320	2,800
3 (CRM 14.5)	620	940	270	—	—	15	19.7
4 (CRM 4.6)	—	860	25	T	—	T	5.8
5 (TRM 602.4)	—	—	—	—	—	—	0.4
6 (TRM 529.9)	—	85	—	T	—	T	1.5
7 (TRM 465.5)[c]	—	250	—	—	T	T	4.4
7 (TRM 465.5)[d]	—	170	—	—	—	T	3.6

[a] Values below limit of detectability.

[b] T indicates trace.

[c] Raw water.

[d] Treated water.

Gamma spectra were obtained of filter sand, as collected and after washing, and of two wash waters. Nuclide concentrations for these samples are shown in table 2–5. The unwashed sand shows cerium-144-praseodymium-144, ruthenium-106-rhodium-106, zinc-65, and cobalt-60, with traces of cesium-137-barium-137m, and zirconium-95-niobium-95. To determine if the radioactivity could be removed from the sand by simple backwashing, the sand sample was placed in an approximately equal volume of water and stirred slowly for about 5 minutes; then the sand was resuspended in about an equal volume of

Table 2–5. Radionuclide Concentrations in Filter Sand and Filter Sand Wash-Water Residue from the Chattanooga Water Treatment Plant, February 1960

[Activities in pc/kg dry weight]

Sample	Ce^{144}-Pr^{144}	Ru^{106}-Nb^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}
Unwashed filter sand	330	5,700	[a] T	T	[b] —	100
Twice-washed filter sand	200	2,200	T	5	30	90
First wash-water residue	[a] 14,000	[c] 120	T	[c] 0.8	—	—
Second wash-water residue	[c] 25	[c] 650	T	—	[a] 5	T

[a] T indicates trace.

[b] Values below limit of detectability.

[c] pc/liter.

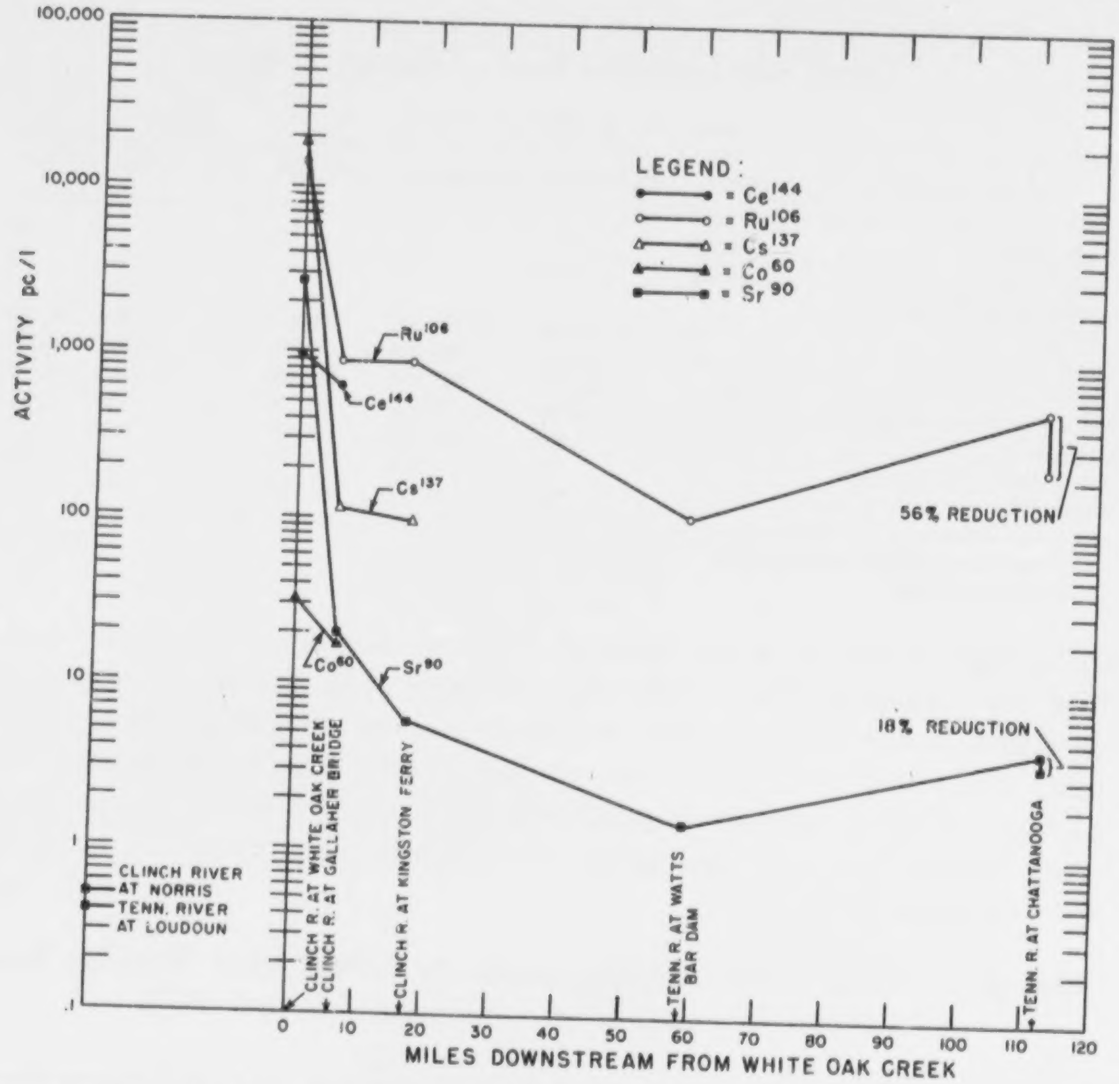

Figure 2–2. Radionuclide Concentrations in Water, Clinch and Tennessee Rivers

water and stirred quite rapidly for approximately 20 minutes to see if attrition between sand grains would remove any activity left on the sand after the first washing. This latter spectrum indicates that the activity arising from ruthenium, cesium, and cobalt is very firmly attached to the sand particles and would be difficult to remove by mechanical means. The type of fixation, however, has not been determined.

BOTTOM SEDIMENTS

The nuclides found in the water also appear in the bottom sediment spectra but in much higher concentrations. Radionuclide concentrations in bottom sediment samples collected from the Clinch and Tennessee Rivers are shown in table 2–6. The nuclide concentrations

Table 2–6. Radionuclide Concentrations in Bottom-Mud Samples from the Clinch and Tennessee Rivers, February 1960

[Activities in pc/kg wet weight]

Sample location	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	Sr^{90}
TRM 602.3	1,600	[a] —	[b] T	100	—	—	280
CRM 79.8	1,200	630	T	100	—	—	75
Mouth of White Oak Creek	2,300,000	2,400,000	8,800,000	76,000	—	510,000	97,000
CRM 20.7	57,000	100,000	360,000	4,100	—	21,000	8,600
CRM 14.6	2,700,000	4,000,000	320,000	240,000	—	250,000	5,000
Mouth of Emory River	2,400	8,000	12,000	T	—	770	900
CRM 4.5	22,000	75,000	100,000	1,800	—	900	260
TRM 529.9	—	T	800	T	—	—	170
TRM 471.0	3,400	5,700	6,900	300	—	890	540

[a] Values below limit of detectability.

[b] T indicates trace.

in bottom muds, as a function of distance, are shown in figure 2–3. The low values at Watts Bar Dam are probably due to scour in this area and to the fact that the sample contained very little clay. The main component was sand, which has a very low ion-exchange capacity. Higher concentrations downstream at the face of Chickamauga Dam resulted from the deposition of transported clays and silt, or from ion exchange *in situ*.

Table 2–7. Radionuclide Concentrations in Bottom-Mud Samples from Clinch and Tennessee River Tributaries, February 1960

[Activities in pc/kg dry weight]

Sampling location	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	Sr^{90} [a]
White Oak Creek Dam	5,000,000	66,000,000	38,000,000	7,300,000	[b] —	2,800,000	1,000,000
Mouth of White Oak Creek (left side)	1,100,000	2,400,000	9,200,000	1,500,000	—	760,000	360,000
Bear Creek at White Wing Rd.	—	—	—	—	—	—	20
Fort Loudoun Lake	—	—	[c] T	—	—	—	300
Bear Creek (rock) at White Wing Rd.	—	—	T	—	—	—	65
Bear Creek, White Wing Rd. & Turnpike	—	—	T	—	—	—	
Bear Creek (gravel)	—	—	T	T	—	—	30
Poplar Creek (left side)	590,000	120,000	5,000,000	30,000	—	340,000	800
Poplar Creek 200 yd. up from mouth	120,000	380,000	430,000	20,000	—	40,000	770
Poplar Creek 200 ft. below K-25	—	—	120,000	—	—	250,000	530
S. Chickamauga Creek	4,800	—	—	680	—	—	330

[a] Sr^{90} values shown only for samples analyzed. Values obtained by radiochemical analyses.

[b] Values below limit of detectability.

[c] T indicates trace.

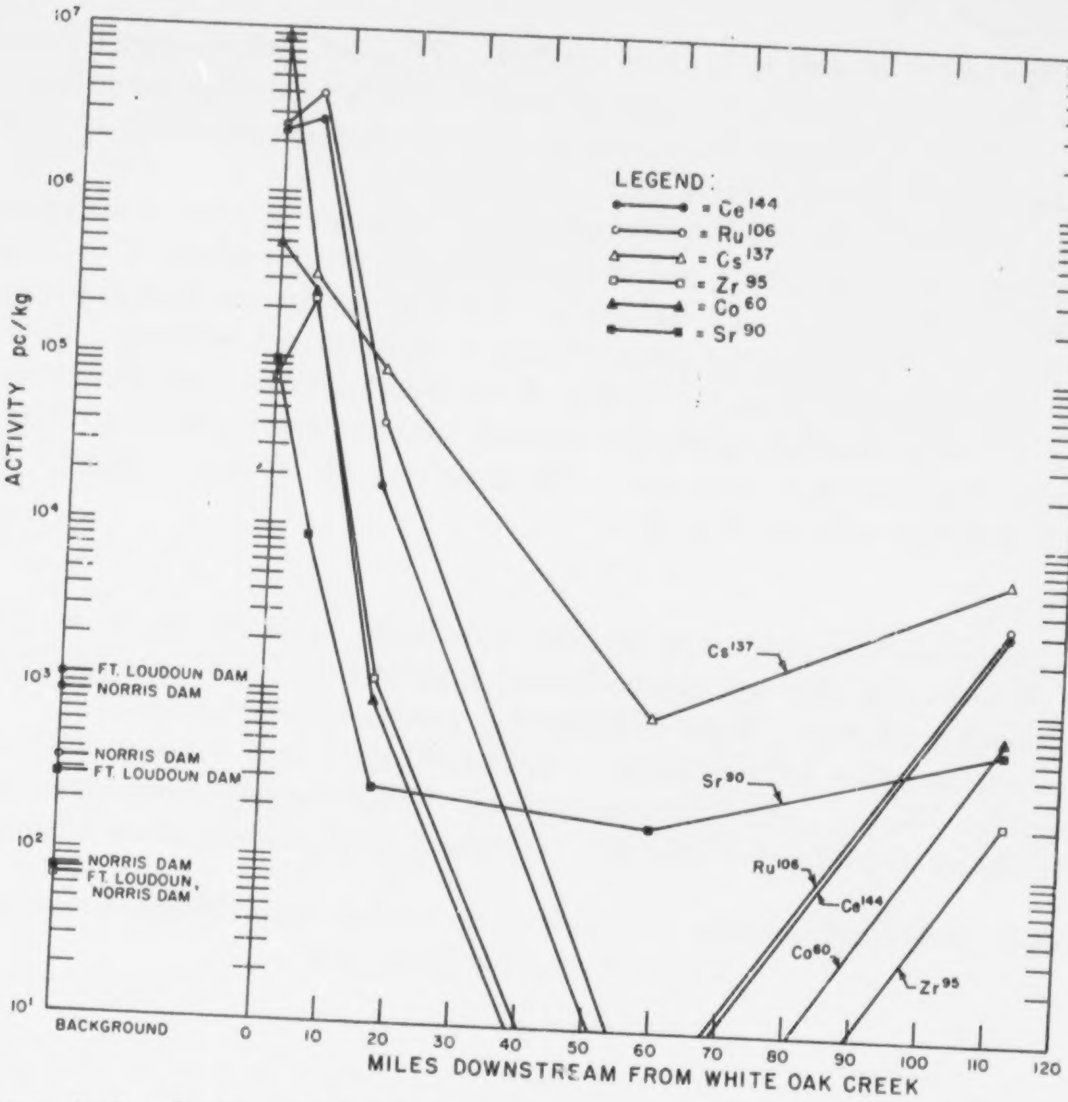

Figure 2–3. Radionuclide Concentrations in Bottom Muds, Clinch and Tennessee Rivers

Radionuclide concentrations in the bottom muds of tributaries are listed in table 2–7. As expected, cerium-144-praseodymium-144, ruthenium-106-rhodium-106, cesium-137-barium-137m, zirconium-95-niobium-95, cobalt-60, and strontium-90 concentrations in White Oak Creek samples are quite high. Nuclides similar to those in White Oak Creek were observed in the Poplar Creek samples, although the concentrations are one or two orders of magnitude lower. Whether the nuclides in the mud at Poplar Creek originated from White Oak Creek, or whether they reflected discharge practices of the gaseous diffusion plant in the K–25 Area on Poplar Creek, was not determined. The data indicate the former premise is more likely since activity levels are lower upstream in Poplar Creek than at the mouth. The Bear Creek samples show some activity owing to decay products of both thorium-232 and uranium-238. The sample collected in Fort Loudoun Lake is similar.

Two heavy-metals industries located on South Chickamauga Creek, just above Chattanooga, might be responsible for the high strontium-90 levels in Tennessee River water at Chattanooga reported by the Basic Water Quality Network.[3]

In Chattanooga, an inquiry about the activity of these industries disclosed that one plant had discontinued operation about 8 months prior to this study. To determine the activity in the bottom sediments of South Chickamauga Creek, a sample was collected about one-quarter mile from the point of confluence with the Tennessee River. The gamma spectrum showed little activity owing to man-made nuclides but indicated the presence of decay products of uranium-238 and thorium-232.

FISH

Large-fish samples were divided into flesh, bone, scales, liver, gill and heart and thyroid, stomach and intestine and contents, and the remaining viscera. Each of these was analyzed separately.

Fish samples from station 1 (Norris Lake) and station 5 (Fort Loudoun Lake) were gamma-scanned. The nuclide concentrations are listed in tables 2–8 and 2–9. These values were used as baseline

Table 2–8. Radionuclide Concentrations in Fish from Norris Lake and Clinch River, February 1960

[Activities in pc/kg live weight]

Sample	Fraction	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	Sr^{90} [a]
Carp (790g)	Flesh	[b] —	—	35	15	—	—	15
	Bone	—	540	370	—	—	—	20
	Scales	—	210	T	260	380	—	20
	Liver	—	[c] T	—	—	—	—	
	Stomach, intestine and contents	—	—	—	—	—	—	
	Ovaries	—	170	T	—	—	—	
	Other viscera	—	390	T	—	—	—	
Quillback carpsucker	Flesh	—	—	—	—	—	—	4.0
	Bone	—	440	—	70	300	—	28.5
	Scales	—	480	110	T	—	—	
	Liver	—	T	T	—	—	—	
	Stomach, intestine and contents	—	T	T	—	—	—	
	Gills	—	—	—	80	—	—	
	Other viscera	—	—	—	—	—	—	

[a] Sr^{90} values shown only for samples analyzed. Values obtained by radiochemical analyses.

[b] Values below limit of detectability.

[c] T indicates trace.

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[3] National Water Quality Network Annual Compilation of Data, PHS Publication No. 663 (1960).

Table 2–9. Radionuclide Concentrations in Fish from Fort Loudoun Lake and Tennessee River, February 1960

[Activities in pc/kg live weight]

Sample	Fraction	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	Sr^{90} [a]
Carp	Flesh	[b] —	—	—	—	140	—	2.9
	Bone	—	—	[c] T	770	3,300	T	37.2
	Scales	—	—	—	T	200	T	46.8
	Liver	—	—	—	100	—	—	
	Stomach, intestine and contents	—	—	— -	—	—	T	
	Gills, heart, and thyroid	—	—	—	70	—	—	
	Other viscera	—	—	—	70	—	T	

[a] Sr^{90} values shown only for samples analyzed. Values obtained by radiochemical analyses.
[b] Values below limit of detectability.
[c] T indicates trace.

data inasmuch as the samples did not reflect any influences from the discharge of White Oak Creek into the Clinch River. In general, nuclide concentrations were low, and the activity probably resulted from fallout on the watershed.

Because fish collected from White Oak Creek (gizzard shad, white bass, and saugers) were small, each species was divided into two fractions only. They were gutted, the insides counted as one sample, and the remainder of the fish counted as another. Radionuclide concentrations in the three species are listed in table 2–10, which shows that the activity levels in the gizzard shad were significantly higher than those in the white bass and saugers. Since the gizzard shad are lower in the food chain than bass or saugers, their feeding habits differ and they accumulate greater quantities of all the nuclides than do the latter.

Table 2–10. Radionuclide Concentrations in Fish from White Oak Creek, February 1960

[Activities in pc/kg live weight]

No. of fish	Sample	Fraction	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	Sr^{90} [a]
51	Gizzard shad (615 g)	Structure	[b] —	43,000	12,000	[c] T	—	3,000	
		Viscera		230,000	19,000	4,500	T	10,00	
3	White bass	Structure	—	8,900	1,800	60	710	—	55
		Viscera	—	21,000	940	140	T	640	
2	Saugers (161 g)	Structure	—	3,600	1,400	—	T	—	15
		Viscera	—	4,200	1,700	140	—	—	

[a] Sr^{90} values shown only for samples analyzed. Values obtained by radiochemical analyses.
[b] Values below limit of detectability.
[c] T indicates trace.

The same nuclides present in the fish from White Oak Creek were found in fish from station 3; however, corresponding levels of activity were appreciably lower in samples from the latter station.

Nuclide concentrations in the component parts of the fish samples from station 3 are shown in table 2–11. The radionuclide concentrations in the game species (skipjack herring, white bass, and saugers) are lower than those in the filter-feeding fish (gizzard shad) and bottom-feeding fish (carp).

Practically all the activity in the carp is tied up with the stomach, and intestines and contents. One might speculate that this fish probably spent most of its time in the Clinch River upstream of White Oak Creek, or in one of the tributaries, and had only recently moved into the area where it was caught. If this were true, then the high ruthenium and cesium concentrations in the intestinal samples would indicate that the radionuclides were taken up with the food, and that the fish had not been able to assimilate and fix them in his body organs to any extent. Conversely, one might assume that the gizzard shad had spent considerable time in waters of high nuclide concentrations.

Nuclide concentrations in two game-fish samples (saugers and smallmouth bass) from station 4 and three bottom feeders (carp, carpsuckers, and smallmouth buffaloes) are shown in table 2–12. The difference in nuclide levels of the two game fish indicates the variation that can exist between sight-feeding fish.

Four catfish, collected from Chickamauga Lake at Hixson by a commercial fisherman, showed no gamma-emitting nuclides, except the decay products of thorium-232 and uranium-238. Strontium-90 levels of 50 and 660 picocuries per kilogram of live weight were found in the flesh and bone, respectively. One might speculate that these fish had spent all their lives in one of the tributaries not affected by discharge practices of ORNL and only recently had migrated into the Tennessee River proper.

A smallmouth buffalo fish from Hales Bar Lake below Chattanooga was gamma-scanned, and nuclide concentrations are determined (table 2–13). All the expected nuclides are present, some at surprisingly high levels, with the exception of cerium-144-praseodymium-144 and cobalt-60.

Gamma spectra of samples of snails, crayfish, clams, and a turtle were obtained, and nuclide concentrations are shown in table 2-14. In some instances the counting geometry was not determined and calculation of radionuclide concentrations was not possible; however, strontium-90 values were obtained for all samples except the turtle. The level of zinc-65 in the snail sample, collected from a small stream flowing into Norris Lake, is significant because only traces were found in other biota samples from other places.

Table 2-11. Radionuclide Concentrations in Fish from Station 3, Clinch River, February 1960

[Activities in pc/kg live weight]

No. of fish	Sample	Fraction	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	Sr^{90} [a]
2	White bass	Flesh	[b] —	—	700	30	[c] T	T	300
		Bone	710	1,000	T	T	—	—	660
		Scales	—	T	T	150	—	—	640
		Liver	—	—	T	—	—	—	
		Stomach, intestine and contents	—	—	700	—	—	—	
		Other viscera	—	T	—	—	—	—	
5	Saugers (780 g)	Flesh	—	—	750	—	—	—	120
		Bone	—	—	T	—	—	—	480
		Scales	—	3,300	320	—	—	—	260
		Liver	—	—	T	—	—	—	
		Gills, heart, and thyroid	—	—	T	—	T	—	
		Other viscera	—	—	520	—	—	—	
14	Gizzard shad (1,100 g)	Flesh	—	—	1,100	—	900	—	14,000
		Bone	720	1,800	1,600	60	710	—	850
		Scales	—	740	470	50	110	170	1,100
		Stomach, intestine and contents	8,400	28,000	14,000	200	—	180	
		Gills, heart and thyroid.	—	2,200	2,600	T	250	—	
		Other viscera	4,400	14,000	46,000	230	660	970	
6	Skipjack herring (990 g)	Scales	—	210	—	—	—	—	160
		Liver	—	—	800	—	—	—	
		Stomach, intestine and contents	—	800	660	—	—	—	
		Gills, heart, and thyroid	—	2,300	75	—	180	—	
		Ovaries and testes	—	T	1,200	T	—	—	
1	Carp (400 g)	Flesh	—	—	430	—	270	—	340
		Bone	—	T	T	—	280	—	1,700
		Scales	—	—	T	—	530	—	1,100
		Liver	—	—	—	T	—	—	
		Stomach, intestine and contents	—	9,400	13,000	T	—	—	
		Gills, heart, and thyroid	—	—	T	—	—	—	
		Other viscera	—	—	T	—	580	—	

[a] Sr^{90} values shown only for samples analyzed. Values obtained by radiochemical analyses.
[b] Values below limit of detectability.
[c] T indicates trace.

Table 2-12. Radionuclide Concentrations in Fish from Station 4, Clinch River, February 1960

[Activities in pc/kg live weight]

No. of fish	Sample	Fraction	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	Sr^{90} [a]
1	Sauger (420 g)	Flesh	[b] —	840	490	[c] T	—	—	70
		Bone	—	—	—	T	—	—	160
		Stomach, intestine and contents	—	2,600	—	T	—	—	
		Other viscera	300	—	T	—	180	—	
1	Smallmouth bass	Flesh	—	—	600	30	65	60	500
		Scales	2,750	950	145	15	95	180	290
		Liver	—	490	370	55	390	—	
		Stomach, intestine and contents	—	1,000	380	25	85	T	
		Gills, heart, and thyroid	—	1,700	—	30	T	120	
		Ovaries	—	—	—	30	—	—	
		Other viscera	—	—	270	—	T	—	
1	Carpsucker (740 g)	Flesh	—	—	320	15	—	—	1,000
		Bone	—	190	25	15	—	—	1,640
		Scales	—	—	—	40	—	—	560
		Liver	—	—	—	—	—	—	
		Stomach, intestine and contents	5,100	30,000	17,000	150	390	770	
		Ovaries	—	—	—	—	—	—	
		Gills, heart and thyroid	—	—	—	35	—	—	
		Other viscera	430	1,600	440	—	90	140	
1	Carp (1,000 g)	Flesh	—	—	460	T	—	—	285
		Bone	—	310	T	—	—	—	808
		Scales	—	—	—	—	—	—	691
		Liver	—	—	—	41	—	—	
		Stomach, intestine and contents	—	—	1,000	77	145	—	
		Ovaries	—	—	660	16	92	100	
		Gills, heart, and thyroid	—	—	—	20	140	—	
		Other viscera	—	—	—	73	—	—	
1	Smallmouth buffalo (770 g)	Flesh	T	—	570	—	—	—	134
		Bone	T	—	650	T	—	T	
		Scales	—	490	—	—	T	—	109
		Liver	—	—	—	—	—	—	
		Stomach, intestine and contents	—	T	T	—	—	T	
		Testes	—	T	T	—	—	—	
		Gills, heart, and thyroid	—	T	T	T	T	T	
		Other viscera	—	—	—	—	—	—	

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[a] Sr^{90} values shown only for samples analyzed. Values obtained by radiochemical analyses.

[b] Values below limit of detectability.

[c] T indicates trace.

Table 2–13. Radionuclide Concentrations in Fish from Hales Bar Lake at Shellmound, February 1960

[Activities in pc/kg live weight]

No. of Fish	Sample	Fraction	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	S^{90} [a]
1	Smallmouth buffalo (440 g)	Flesh	[b] —	2, 600	180	—	—	—	6. 3
		Bone	—	1, 400	160	—	70	—	310
		Scales	—	—	[c] T	—	—	—	
		Liver	—	—	230	100	150	—	
		Stomach, intestine and contents	—	4, 400	210	—	—	—	
		Gills, heart, and thyroid	—	—	T	—	—	—	
		Other viscera	—	—	T	55	110	—	

[a] Sr^{90} values shown only for samples analyzed. Values obtained by radiochemical analyses.

[b] Values below limit of detectability.

[c] T indicates trace.

Table 2–14. Radionuclide Concentrations in Miscellaneous Biota from the Clinch and Tennessee Rivers, February 1960

[Activities in pc/kg live weight]

Sample	Sample location	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Zr^{95}-Nb^{95}	Zn^{65}	Co^{60}	Sr^{90} [a]
Snails	Norris Lake	[b] —	[c] T	—	—	2, 200	—	140
Crayfish	Norris Lake	—	—	—	—	—	—	120
Clam	Clinch River above White Oak Creek	—	T	—	T	—	—	35
Turtle	CRM 14.6	[d] +	—	+	+	T	—	
Clam shell	TRM 529.9	T	T	T	T	T	—	1, 100

[a] Sr^{90} values shown only for samples analyzed. Values obtained by radiochemical analyses.

[b] Values below limit of detectability.

[c] T indicates trace.

[d] (+) Values indicate presence of nuclides, but counting efficiency not determined.

Conclusions

Concentration factors given in table 2–15 appear to follow the expected food chain relationships, with the highest concentrations in gizzard shad, a definite plankton feeder, which eats organisms that are primary accumulators of radionuclides. The factors for bottom feeders are somewhat lower, and those for the game fish are the lowest.

Table 2–16 lists the strontium-90 activities of various components of fish collected from White Oak Creek and the Clinch and Tennessee Rivers. Column 5 shows the concentration factors of these various component parts in relation to the concentration of strontium-90 in water on an equal weight basis. Column 6 shows the ratio of strontium-90 in bones to that in flesh, also on an equal weight basis. These data show that fish concentrate strontium-90 by factors of 10 to 100, with the highest concentrations in the calcareous tissues, the bones, and the scales. The ratios of strontium-90 in bones to those in flesh (col. 6) vary from 0.6 to 13.4, with an average ratio of 3.6 for the nine pairs of samples.

Table 2–15. Radionuclide Concentration[a] Factors in Fish from the Clinch and Tennessee Rivers

Sample	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Co^{60}
	Station 2			
Gizzard shad	[b]—	10.4	7.4	22
White bass	—	0.8	0.8	0.5
Saugers	—	0.3	0.7	—
	Station 3			
White bass	0.13	0.1	1.5	—
Saugers	—	0.6	1.6	—
Gizzard shad	3.2	6.9	44	14
Skipjack herring	—	0.9	1.1	—
Carp	—	0.5	2.8	—
	Station 4			
Saugers	—	0.8	12	—
Smallmouth bass	—	0.7	11.5	—
Smallmouth buffaloes	—	0.1	8.7	—
Carp	—	0.1	13.5	—
Carpsuckers	—	1.9	37.0	—
	Station 7			
Buffaloes	—	6.1	—	—

[a] $\frac{\text{pc/kg live weight of total fish}}{\text{pc/l water}}$

[b] Values below limit of detectability.

Table 2–17 lists the amount of activity in the water phase passing stations 1, 3, 4, 5, 6, and 7 daily and represents the product of the values reported in table 2–4 and the estimated flow of the river in liters per day at the particular station.

The river flows at stations 1, 3, and 4 are the average of mean weekly discharges at Norris Dam for February in the years 1939–1945; at station 5 similar discharge values at Fort Loudoun Dam were used; at station 6 discharge values at Watts Bar Dam; and at station 7 discharge values at Hales Bar Dam.[4]

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[4] The data were taken from the publication, "Engineering Data, Tennessee Valley Authority Projects, Technical Monograph No. 55," January 1947.

Table 2–16. Sr^{90} Concentration Factors for Various Components of Fish from White Oak Creek and the Clinch and Tennessee Rivers

Species	Fraction	Station	Water conc. (pc/l)	Activities (pc/kg live wt)	Conc. factor: pc/kg live wt / pc/l water	Ratio: bone / flesh
White bass	Structure	2	2,825	56	0.02	
Saugers	Structure	2	2,825	16	.005	
White bass	Bone	3	19.7	665	33.8	2.2
	Flesh			298	15.1	
	Scales			635	32.2	
Saugers	Bone			485	24.6	4.2
	Flesh			115	5.8	
	Scales			263	13.4	
Gizzard shad	Bone			850	43.2	0.6
	Flesh			1,365	69.3	
	Scales			1,080	54.8	
Skipjack	Scales			162	8.2	
Carp	Bone			1,715	87.1	5.0
	Flesh			340	17.3	
	Scales			1,080	54.8	
Saugers	Bone	4	5.8	155	26.7	2.2
	Flesh			69	12.0	
Smallmouth bass	Bone			336	57.9	0.7
	Flesh			500	86.2	
	Scales			291	50.2	
Smallmouth buffaloes	Flesh			134	23.1	
	Scales			109	18.8	
Carp	Bone			808	139.3	2.8
	Flesh			285	49.1	
	Scales			691	119.1	
Carpsuckers	Bone		5.8	1,640	283	1.6
	Flesh			1,030	173	
	Scales			557	96	
Catfish	Bone	7	4.4	665	151	13.4
	Flesh			49.7	11.3	

Table 2–17 indicates that cerium-144-praseodymium-144, cesium-137-barium-137m, and cobalt-60 disappear from the water phase during the first 15 miles of river flow, while ruthenium-106-rhodium-106 and strontium-90 are retained in the water longer. The total activity reported at each station does not decrease consistently with distance or time of flow, as one might expect in a natural waterway with a constant uptake of these radionuclides by the associated environmental media. In fact, terminal values for gross amounts of these nuclides are larger than those reported upstream. Such anomalies probably result from the operation of manmade controls on these streams at Watts Bar and Chickamauga Dams and from the methods of collecting the water samples.

There are no manmade controls in the Clinch River between stations 3 and 4. If the values for these samples, which were collected by similar methods and at similar depths are compared (table 2–17), a diminution of activity for each of the nuclides is shown at the downstream station, and the anomalies mentioned previously disappear.

The numbers in parentheses after the ruthenium-106-rhodium-106 values at stations 3, 4, 6, and 7 are the gross ruthenium-106-rhodium-106 activities divided by the gross strontium-90 activities at these individual locations. The relative constancy of these ratios indicates that there is little difference in the behavior of these radionuclides in this river system after about 6 miles of flow.

Table 2–17. Calculated Activities Carried in the Water Past Each Station Per Day

[Activities in curies/day]

Est. flow/day	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Cs^{137}-Ba^{137m}	Co^{60}	Sr^{90}
Station 1, 1.8×10^{10}	[a] —	—	—	—	0. 009
Station 3, 1.8×10^{10}	11. 25	16. 95 [b] (48. 5)	0. 88	0. 31	0. 35
Station 4, 1.8×10^{10}	—	5. 82 [b] (58. 2)	0. 50	—	0. 10
Station 5, 5.1×10^{10}	—	—	—	—	0. 02
Station 6, 11.1×10^{10}	—	9. 6 [b] (57. 7)	—	—	0. 166
Station 7, 13.7×10^{10}	—	53 [b] (88. 4)	—	—	0. 6

[a] Values below limit of detectability.

[b] Gross Ru^{106}-Rh^{106} activity divided by gross Sr^{90} activity.

Table 2–18 shows the nuclide activities in samples of unwashed filter sand, washed sand, and the two wash-waters from the Chattanooga Water Treatment Plant. Suspension of the sand during backwashing apparently removes very little cerium-144-praseodymium-144 and cobalt-60, and only about 8 percent of the ruthenium-106-rhodium-106. Laboratory findings show that more vigorous backwashing, e.g., air washing, removes much more of the absorbed activity on the sand grains connected with silts or bacterial growths, owing to attrition between the sand grains. The fact that recoveries of over

100 percent occurred is attributed to increased efficiency due to separation of the activity from the sand particles. Counting the activity in the absence of particles would tend to reduce self absorbtion and increase counting efficiencies.

Table 2–18. Activities in Filter Sand and Wash-Water Samples From Chattanooga Water Treatment Plant

[Activities in pc/sample]

Samples	Ce^{144}-Pr^{144}	Ru^{106}-Rh^{106}	Co^{60}
Unwashed sand	212	3, 675	65
Washed sand	126	1, 470	56
First wash-water	[a]—	280	—
Second wash-water	89	2, 300	2
Total activity in latter three samples	215	4, 050	58
Percent recovery	101	110	112

[a] Values below limit of detectability.

SECTION III: LABORATORY STUDIES

Uptake studies were performed to determine the effects of parameters, such as temperature, activity levels, and stable ion concentrations, on strontium-85 and cesium-137 uptake by guppies (*Lebistus reticulatus*), bluegills (*Lepomis gibbosus*), algae, and snails.

All investigations were set up as factorial experiments, and results were analyzed in cooperation with the Statistical Services Section at the Robert A. Taft Sanitary Engineering Center.

Experimental Methods

The first experiment, an individual aquarium type, was designed to determine the effects of temperature, stable calcium, stable strontium, and strontium-85 concentrations on the uptake of strontium-85 by growing fish. The fish used were guppies.

The actual design of the experiment, with (+) denoting high and (−) denoting low values for the parameters, follows:

Tank No.	*Calcium concentration*	*Strontium concentration*	*Strontium-85 activity*	*Temperature*
1	+	+	+	+
2	+	+	−	−
3	+	−	−	+
4	+	−	+	−
5	−	+	−	+
6	−	+	+	−
7	−	−	+	+
8	−	−	−	−

In the first phase:

Calcium (+)=50 mg/l as Ca^{++}	Calcium (−)=5 mg/l as Ca^{++}
Strontium (+)=50 mg/l as Sr^{++}	Strontium (−)=5 mg/l as Sr^{++}
Strontium-85 (+)=50 pc/ml as Sr^{++}	Strontium (−)=5 pc/ml as Sr^{++}
Temperature (+)=30° C.	Temperature (−)=20° C.

The second phase of the experiment consisted of changing activities originally at high levels to low levels and low levels to high.

The concentrations of the stable ions, and the strontium-85 levels were measured and adjusted to their original value at weekly intervals.

The experiment began with eight tests and eight combinations of conditions, a one-half replicate of a factorial experiment with four variables. However, three tests had to be discontinued because of the death of most of the fish in the tanks, caused by the malfunctioning of the electrically controlled thermostats which resulted in overheating the aquaria.

The radioactivity of the fish was determined by placing all the fish from a single tank in a plastic weighing bottle containing 25 milliliters of water. The weighing bottle was then placed on a shielded 2- by 2-inch codium iodide (Tl) crystal connected to a single-channel gamma spectrometer, so adjusted as to register only those pulses from the strontium-85 gamma emissions (0.513 Mev.).

A second set of experiments followed these tests. A 2^3 factorial experiment was performed with guppies by use of the following design:

Tank No.	*Conc. of* Sr^{85}	*Conc. of stable Ca*	*Conc. of stable Sr*
1	+	+	+
2	+	+	−
3	+	−	+
4	+	−	−
5	−	+	+
6	−	+	−
7	−	−	+
8	−	−	−

Note: Each tank contained 15 fish.

Strontium-85 (+)=500 pc/ml as Sr^{++}
Calcium (+)=50 mg/l as Ca^{++}
Strontium (+)=50 mg/l as Sr^{++}

Strontium-85 (−)=50 pc/ml as Sr^{++}
Calcium (−)=1 mg/l as Ca^{++}
Strontium (−)=1 mg/l as Sr^{++}

Weekly counts of the amount of radioactive strontium in the fish and in the water were made, and the tanks were redosed individually to bring the activity concentrations back to the original high or low levels. For all eight tanks, weekly counting was continued until an examination of the graphed data showed no time trends in the counts during the last four counting periods. The experiment was discontinued and the last three fish counts for each tank were examined statistically.

In the statistical analyses, a fourth factor (D_i=date of counting, where i=1, 2, 3) was introduced to guard against the possibilitythat systematic time trends might inflate the estimate of the experimental error. Because no trends were found, the groups of three counts were considered replicates (obtained under stable conditions), and the experimental error was measured as variation between replicates.

At least four fish were always counted as a group, except in tank 6, where only one fish survived to be counted during the last 3 weeks. Weights of fish varied from 0.034 gram (1 fish, tank 6) to 0.326 gram (12 fish, tank 2).

The third study was a 2^4 factorial experiment replicate with high and low values of the stable ions of calcium, strontium, cesium, and potassium. High and low values for each of the four variables were 20 milligrams per liter and 0.1 milligram per liter, respectively. Sixteen aquaria were set up, each containing 20 liters of distilled water, buffered to pH 6.8 with saturated sodium phosphate solution. Stable salts were added to the 16 aquaria as follows so that all possible combinations of high (+) and low (−) values of the stable ions were obtained:

Tank No.	*Cs*$^+$	*Ca*$^{++}$	*K*$^+$	*Sr*$^{++}$
1	−	−	−	−
2	+	−	−	−
3	−	+	−	−
4	+	+	−	−
5	−	−	+	−
6	+	−	+	−
7	−	+	+	−
8	+	+	+	−
9	−	−	−	+
10	+	−	−	+
11	−	+	−	+
12	+	+	−	+
13	−	−	+	+
14	+	−	+	+
15	−	+	+	+
16	+	+	+	+

Seven or eight 2-inch bluegills and six ramshorn snails were placed into each aquarium. The fish were fed daily on ground dog-biscuit. Samples of the water, fish, and snails were counted on a 20-channel gamma spectrometer after 2 days and at weekly intervals thereafter. The fish and snails were sacrificed for counting; the snails were separated into two parts, flesh and shell.

The fourth experiment was a study of strontium and cesium uptake by bluegills, snails, and algae in a balanced aquarium system. The 2^4 factorial experiment was designed to show the effects of the concentrations of the four cations (Cs^+, K^+, Sr^{++}, and Ca^{++}) on uptake by fish, snails, and algae of strontium-85 and cesium-137 from an aqueous solution. The procedure consisted of maintaining the organisms in water containing varying concentrations of stable cations at predetermined activity levels of strontium-85 and cesium-137. The organisms, which were sacrificed for counting, and the water were counted at weekly intervals on a 20-channel gamma spectrometer. Samples were placed in a plastic container and placed directly upon the sodium iodide crystal.

Before counting, a 10-minute background count was made, which was subtracted from each sample count. This value was recorded as net count. The spectrometer was set so that both the cesium-137 and strontium-85 peaks were well within the 20-channel range. A correction factor was applied to the strontium-85 count by subtracting 35 percent of the net cesium value in cpm from the net strontium count. The value, 35 percent, was determined experimentally.

Sixteen aquaria were used, each containing a different possible combination of high and low concentrations of stable salts of four cations: $CaCl_2$, KNO_3, $SrCl_2$, and $CsNO_3$. The low concentration (−) of each of the stable salts was 0.02 milligram per liter and the high concentration (+) of each salt was 20 milligrams per liter, as shown below:

Tank No.	Cs^+	Ca^{++}	K^+	Sr^{++}
1	−	−	−	−
2	+	−	−	−
3	−	+	−	−
4	+	+	−	−
5	−	−	+	+
6	+	−	+	−
7	−	+	+	−
8	+	+	+	−
9	−	−	−	+
10	+	−	−	+
11	−	+	−	+
12	+	+	−	+
13	−	−	+	+
14	+	−	+	+
15	−	+	+	+
16	+	+	+	+

After the salts were added to distilled water, a quantity of algae and six to eight fish and snails were put into each aquarium. Strontium-85 and cesium-137 in concentrations of 1,000 picocuries per milliliter were added to each aquarium on day-zero.

Sampling was according to the following schedule:

Medium	Sampling day 1	6	9	13	16	20	23	27
Algae	x	x	x	x	x	x	x	
Whole fish	x	x		x		x		
Snail flesh	x	x		x		x		
Snail shell	x	x		x		x		x
Water	x	x		x		x		x

Thus, except for occasional missing values, the uptake data for each type of medium were arranged in a complete $2^4 \times k$ factorial design, where k is the number of different days on which samples of a particular medium were taken.

Statistical analysis of the results was accomplished by the following methods. Following a logarithmic transformation to stabilize the variance of experimental errors, an analysis of variance was made.

In the design of the experiment, in order to provide an independent estimate of the amount of experimental error, no tests were duplicated; so the error variance was taken to be the pooled variance of all four-factor and five-factor interactions that involved "time" (sampling days) as a factor. Such interactions measure the inconsistency from sampling day to sampling day of the high-order interaction effects between groups of three and four stable salts; the ion effects are usually nil except for the contributions of experimental errors. The experimental error, measured as described, was fairly uniform for all media, which tends to confirm the validity of the procedure.

On the average, unexplained variability (i.e., experimental error) in the logarithm of uptake by snails was about twice as large as the amount of unexplained variability in uptake by fish or algae. This was true for both strontium-85 and cesium-137.

When a few values were missing in an experiment, they were estimated by the method of least squares. In two cases, so many values were missing for one particular sampling day that estimating the missing values was not feasible, so all the data from the sampling day were discarded. The data discarded were:

Medium	Sampling day	No. of missing values (out of 16 discarded)
Snail flesh, Sr^{85}	Day-27	7
Snail flesh, Cs^{137}	Day-27	7

The following numbers of missing values were estimated by least squares:

Medium	No. of values estimated	
	Sr^{85}	Cs^{137}
Algae	3	None
Whole fish	None	None
Snail shell	4	4
Snail flesh	3	3

Seven counts of strontium-85 in snail flesh were recorded as zero; one of these occurred on day-6 and six occurred on day-13. Two counts of cesium-137 in snail shells were recorded as zeros, both on day-13.

These zero values are entirely inconsistent with the uptake pattern in the rest of the experiment and, since zeros are not acceptable values for statistical analysis, counts of 4.5 picocuries per gram were arbitrarily inserted. This was considered the highest count that could conceivably be mistaken for zero because of experimental error. This procedure invalidates the analysis of those data and, therefore, the results reported for snail flesh (strontium-85) and snail shell (cesium-137) should be looked upon as suggestive, not definitive. It is possible that the zero values could have occurred as a result of overcorrection for the cesium contribution to the strontium peak. However, this does not explain the few zero values for cesium. The experimental error for these two experiments, after making the arbitrary substitutions for zero values, was about twice as high as for the two snail experiments with no zero counts, and about four times as high as for the fish and algae experiments. The large amount of apparent experimental error helps guard against making unwarranted conclusions, but also masks legitimate effects that might have shown up if the error were smaller.

Results and Discussion

Data for the first one-half replicate experiment are presented in table 3–1.

The data obtained for three sets of conditions over the time of the experiments are plotted in figure 3–1. One curve shows the activities of the fish in tank 7, in which conditions were most favorable for uptake. The intermediate level shown was from tank 4 with high stable calcium concentration and high activity levels and low stable strontium concentration and low temperatures (20° C.). Tank 8, with high concentrations of stable calcium and strontium and low activity levels and low temperature, was least favorable for uptake. The latter results are plotted but the counting errors were so large that as a result of the low activities any significant uptake was obscured. The rapid decrease in the activity of the fish after the lowering of activity level of the water is evident from the two upper curves.

Results of the second set of experiments showed that, with low levels of activity (50 pc/ml of strontium-85), varying the concentration of stable calcium did not affect the amount of uptake of strontium-85. However, stable strontium did affect uptake of strontium-85. The geometric average uptake of strontium in the presence of a stable strontium concentration of 50 milligrams per liter was 2,013 counts per minute per gram, but, with a concentration of only 1 milligram per liter, average uptake of strontium–85 was 363 counts per minute per gram. Thus, increasing the stable strontium concentration fifty-fold effected a 2013/363=5.5-fold increase in uptake.

Table 3–1. Results of Controlled Aquarium Study Uptake of Sr^{85} by Guppies After Various Times

Tank 1		Tank 2		Tank 3		Tank 4		Tank 5		Tank 6		Tank 7		Tank 8	
Time days	cpm/g	Time days	cpm/g	Time days	cpm/g	Time days	cpm/g	Time days	cpm/g	Time days	cpm/g	Time days	cpm/g	Time days	cpm/g
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.69	3	0.50	10	0	3	0.80	7	10	3	3.54	3	1.75	3	0.16
10	1.30	7	0.17	17	0	7	0.73	10	0.65	7	5.57	7	3.30	10	0.38
16	0.72	12	0.22	23	0	12	0.24	14	0	10	6.10	12	2.90	17	0.18
18	0.74	18	0.18	25	0	18	0.49	21	0	15	5.40	18	3.35	24	0.16
22	0.81	23	0	29	0.36	23	0.70	27	0	22	4.60	23	3.65	31	0.40
25	0.99	26	0	32	0.05	26	1.15	29	0	29	4.10	26	3.72	38	0.75
29	0.96	30	0	36	0.22	30	1.30	33	3.50	36	*—	30	3.90	45	0.91
32	1.72	33	0.04	39	0.13	33	1.70			42	5.70	33	4.40	52	2.91
35	1.82	37	0.17	—	—	37	1.50			49	5.10	37	5.30	59	1.89
42	2.02	40	—	—	—	40	2.40					40	5.16	68	2.00
49	2.30	44	0.31	—	—	44	2.30					44	5.16	80	1.89
56	2.63	51	—	—	—	51	3.70					51	6.80		
63	2.75	58	0.05	—	—	58	3.50					58	6.60		
						65	3.95					65	6.20		
						72	2.72					72	6.00		
						74	1.90					74	5.00		
						79	—					79	—		
						86	0.70					86	1.56		

* Values below limit of detectability.

With higher levels of activity (500 pc/ml strontium-85), uptake of strontium-85 was 7.2 times as high, on the average, in the presence of 50 milligrams per liter stable strontium as a concentration of 1 milligram per liter. However, the effect of stable strontium varied significantly, depending on how much stable calcium was present. When 1 milligram per liter stable calcium was present, a fiftyfold increase in the concentration of stable strontium caused a fourfold increase in uptake of strontium-85, whereas when 50 milligrams per liter stable calcium was present, increasing the stable strontium concentration caused a 12.8-fold increase in uptake of strontium-85. Geometric averages of three uptakes of strontium-85 per each of four treatments are listed in table 3–2 for the 500 picocuries per milliliter concentration of strontium-85.

A particularly interesting result is that the uptake of the 500 picocuries per milliliter concentration of strontium-85 was 1.27 times as high, on the average, as was the uptake of the 50 picocuries per milliliter concentration of strontium-85. This 27-percent increase can be explained by experimental error alone, and there might well be no increase in uptake with the higher concentration compared to the lower concentration if the experiment were to be repeated. In other words, the fish did not take up a significantly larger amount of activity

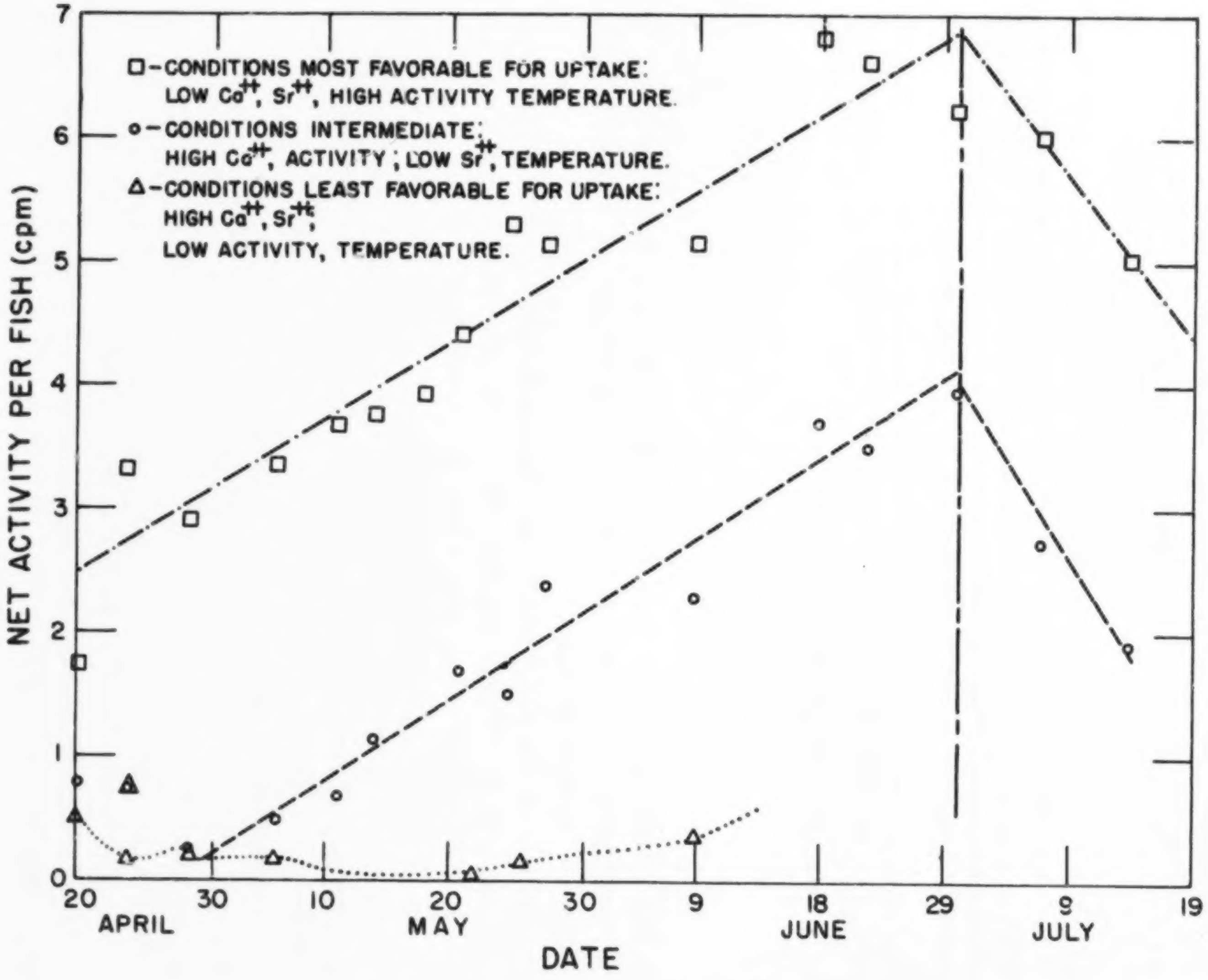

Figure 3–1. Sr^{85} Activities in Fish During Uptake in Experiment 1

Table 3–2. Geometric Average Uptakes of Sr^{85} by Fish

[From 500 pc/l medium]

Concentration			Geometric average
Stable Sr^{++}	Stable Ca^{++}		
	1 mg/l	50 mg/l	
1 mg/l	788 cpm/g	208 cpm/g	405 cpm/g
50 mg/l	3,146 cpm/g	2,669 cpm/g	2,897 cpm/g
Geometric average	1,574 cpm/g	745 cpm/g	

Note: Average effect of an increase in stable $Sr^{++}=2897/405=7.2$-fold increase in uptake of Sr^{85}. Average effect of an increase in stable $Ca^{++}=745/1574=0.47$, factor of decrease in uptake of Sr^{85}.

from the hotter solutions than from solutions with only one-tenth as much strontium-85. This shows the importance of using specific activities for uptake studies.

The results of the third study are shown in table 3–3 and in figures 3–2 through 3–9. These figures show the effects of high and low values of a single element under selected conditions. A dashed line indicates that the ion tested is at the low level; and a solid line, at the high level. A comparison of the dashed and solid lines indicates that, if similar lines (i.e., solid or dashed) occur in pairs, the ion tested has little or no effect on uptake. Figure 3–4 is an example of similar curves appearing in pairs; figure 3–3, of dissimilar curves in pairs.

Figure 3–2 shows the effects of varying stable cesium concentrations on uptake of strontium at both high and low levels of the other three cations being tested. Curves 1 and 2 indicate strontium uptake at an order of magnitude greater than that shown in curves 15 and 16. From this it can be concluded that cesium did not affect strontium uptake, but the combined effect of increasing K^{+}, Sr^{++}, and Ca^{++} was to lower strontium-85 uptake.

Figure 3–3 compares the effect of potassium on strontium uptake. The pairs of dissimilar curves are almost identical. The stable ion concentrations are all identical except those of potassium, which are the extreme values in both instances. These curves show that potassium has little or no effect on strontium uptake under these conditions.

Table 3–3. Activities in Bluegills Kept in Water Containing Various Stable Salts and Sr^{85} and Cs^{137}

Aquarium No.	2-day exposure		9-day exposure		19-day exposure	
	Sr^{85}	Cs^{137}	Sr^{85}	Cs^{137}	Sr^{85}	Cs^{137}
	cpm/g	cpm/g	cpm/g	cpm/g	cpm/g	cpm/g
1	1, 014	53	1, 592	699	1, 858	854
2	1, 985	110	2, 493	521	2, 178	251
3	160	155	447	2, 189	564	1, 802
4	106	18	421	151	468	270
5	1, 524	45	1, 622	211	1, 885	221
6	1, 124	60	2, 275	221	1, 558	166
7	199	26	370	83	506	190
8	167	20	456	83	328	105
9	448	87	718	207	599	439
10	544	20	1, 360	136	912	205
11	122	76	533	738	338	653
12	95	12	316	63	379	180
13	607	64	1, 032	103	898	191
14	804	28	1, 050	184	1, 343	218
15	127	26	295	104	331	141
16	127	16	217	87	309	166

The effects of varying the concentrations of calcium on strontium uptake at both high and low concentrations of cesium, strontium, and potassium are shown in figure 3–4. The dashed lines representing high calcium concentrations appear as one pair, while the solid lines representing low calcium concentrations appear as another pair an order of magnitude higher, indicating that high calcium concentrations tend to suppress uptake of strontium-85.

Figure 3–5 shows the effects of strontium concentration on strontium uptake at high and low levels of calcium, cesium, and potassium. Curves 9 and 16 indicate that increasing the concentration of stable strontium suppresses the uptake of strontium-85, owing to isotopic dilution.

Figures 3–6 through 3–9 show the effects of stable calcium, strontium, cesium, and potassium ion concentrations on cesium-137 uptake for the same experiment. Generally, the conclusions drawn for the cesium-potassium relationship are similar to those for strontium and calcium. Where there is an abundance of potassium, cesium is not taken up to a great extent and, conversely, cesium appears to be taken up and utilized by the fish where low potassium concentrations exist. This is shown in figures 3–6 through 3–9 where, in every instance at high values of potassium, cesium uptake is low; and at low potassium concentrations cesium uptake is always greater. Cesium concentrations affect cesium-137 uptake only when potassium concentrations are low, as shown in figure 3–6 by comparing curves 1 and 15 with 2 and 16, respectively.

Figures 3–8 and 3–9 show the effects of calcium and strontium concentrations on cesium uptake. This experiment shows that, in concentrations used, stable calcium and strontium have little or no effect on cesium uptake.

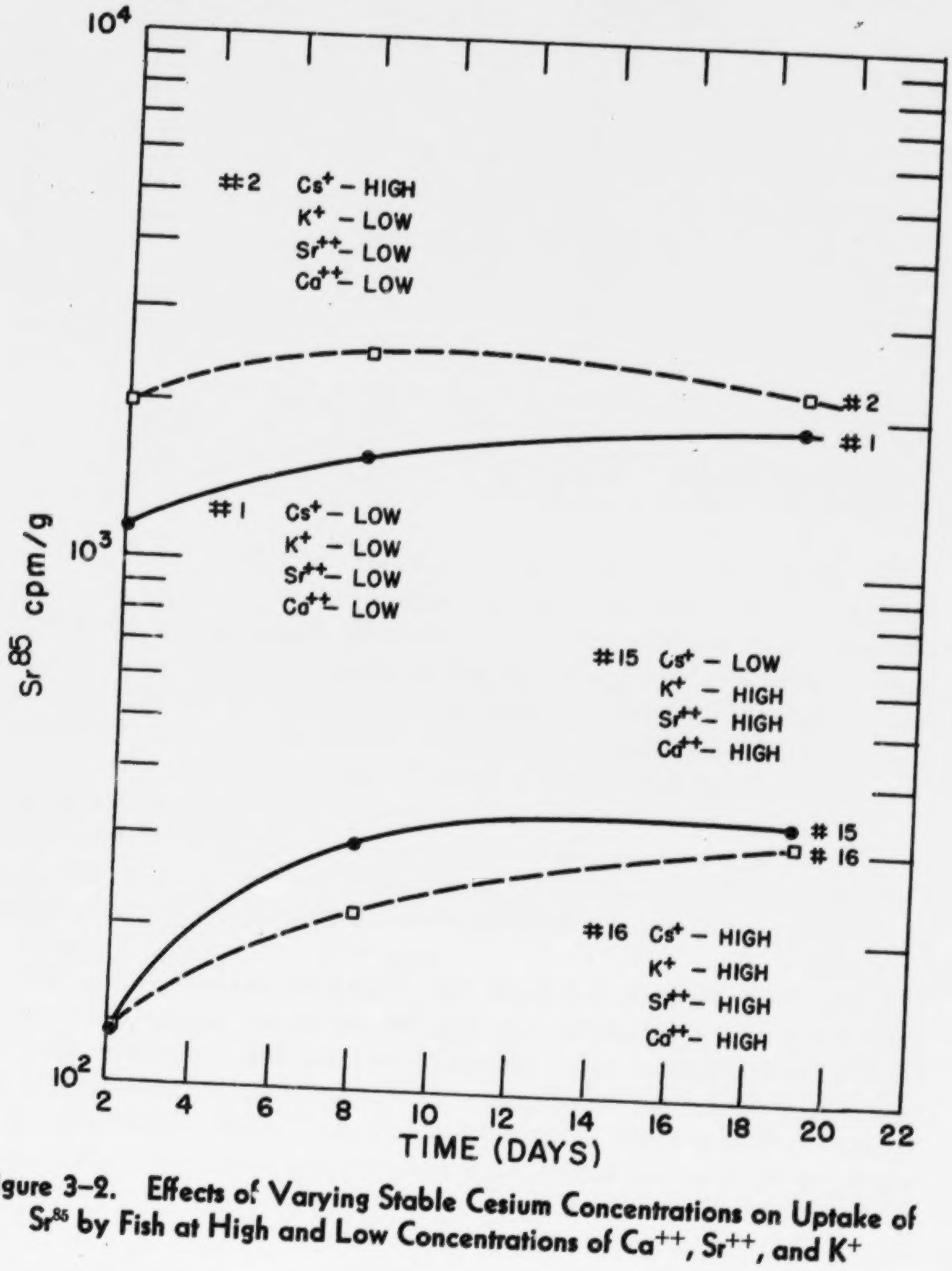

Figure 3–2. Effects of Varying Stable Cesium Concentrations on Uptake of Sr^{85} by Fish at High and Low Concentrations of Ca^{++}, Sr^{++}, and K^+

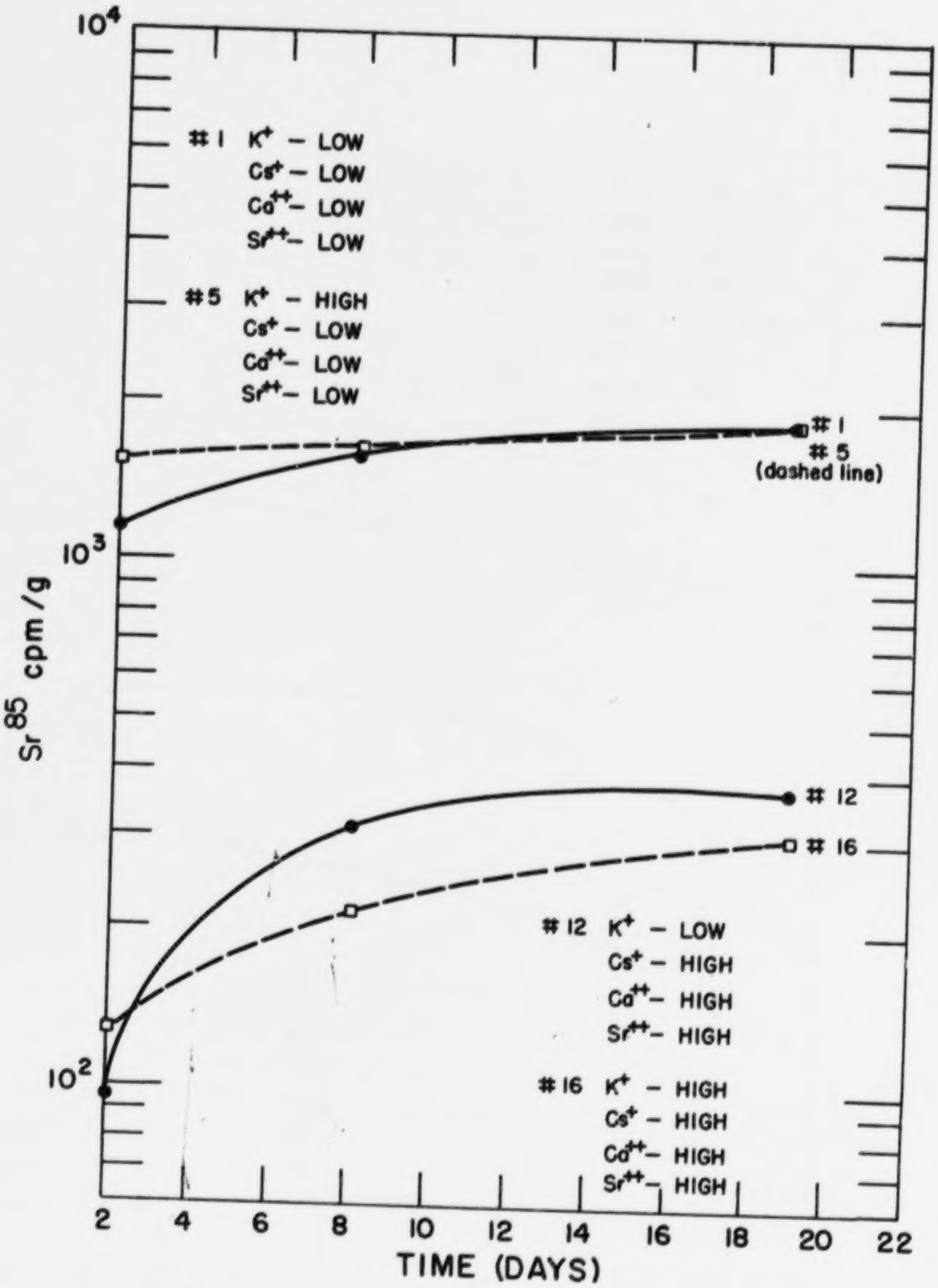

Figure 3-3. Effects of Varying Stable Potassium Concentrations on Uptake of Sr^{85} by Fish at High and Low Values of Cs^+, Ca^{++}, and Sr^{++}

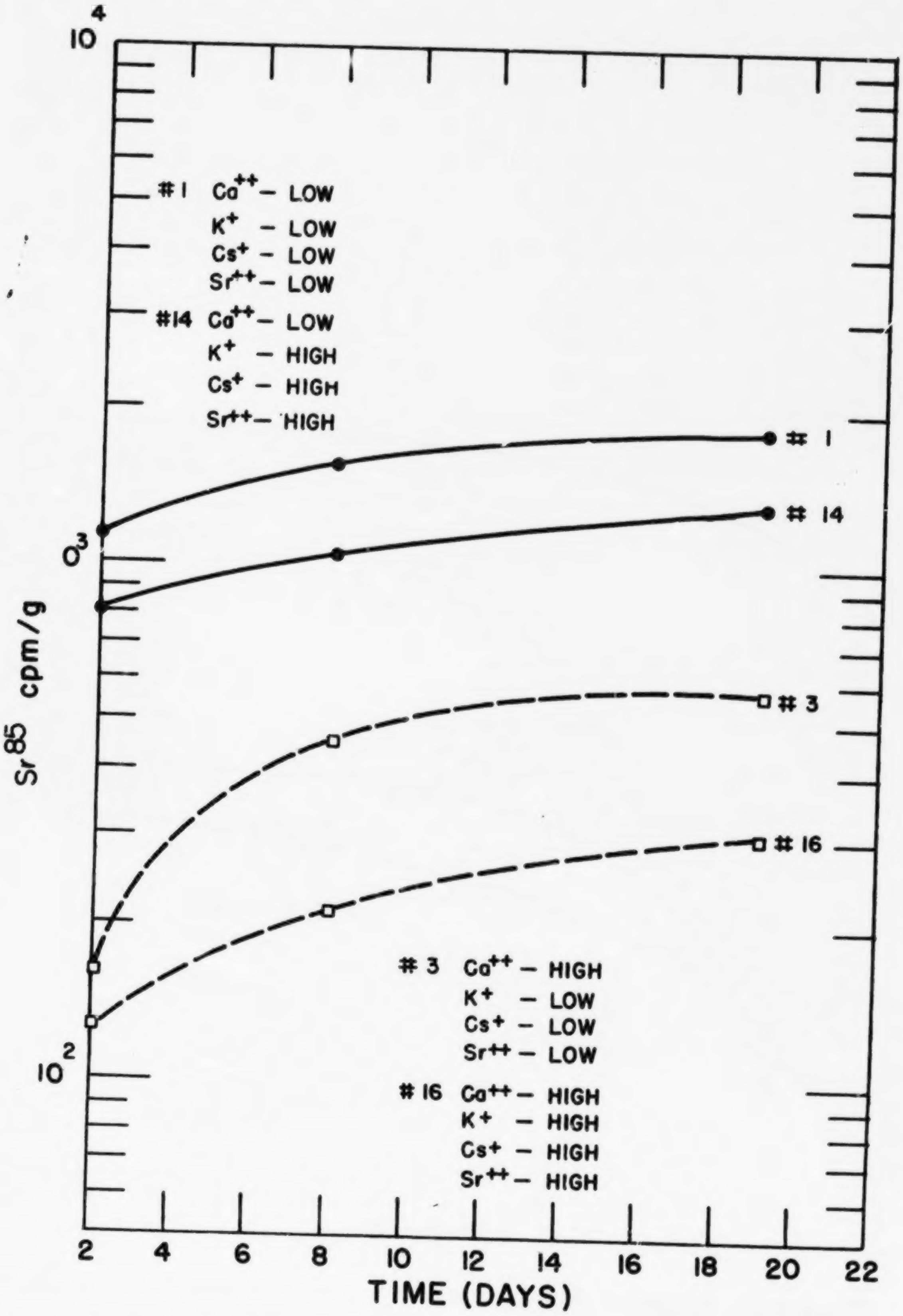

Figure 3–4. Effects of Varying Stable Calcium Concentrations on Uptake of Sr^{85} by Fish at High and Low Values of Cs^+, Sr^{++}, and K^+

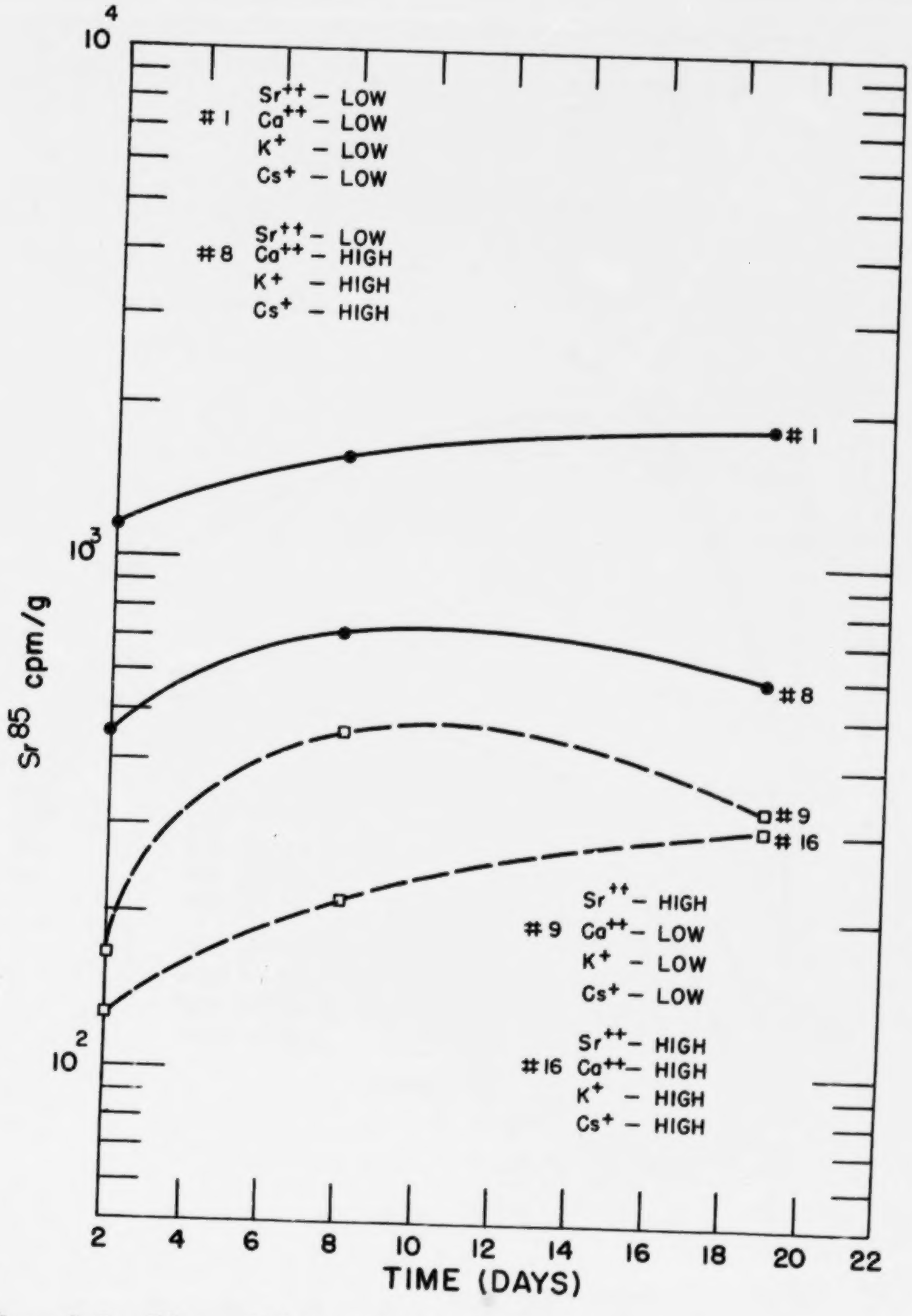

Figure 3–5. Effects of Varying Stable Strontium Concentrations on Uptake of Sr^{85} by Fish at High and Low Levels of Ca^{++}, Cs^{+}, and K^{+}

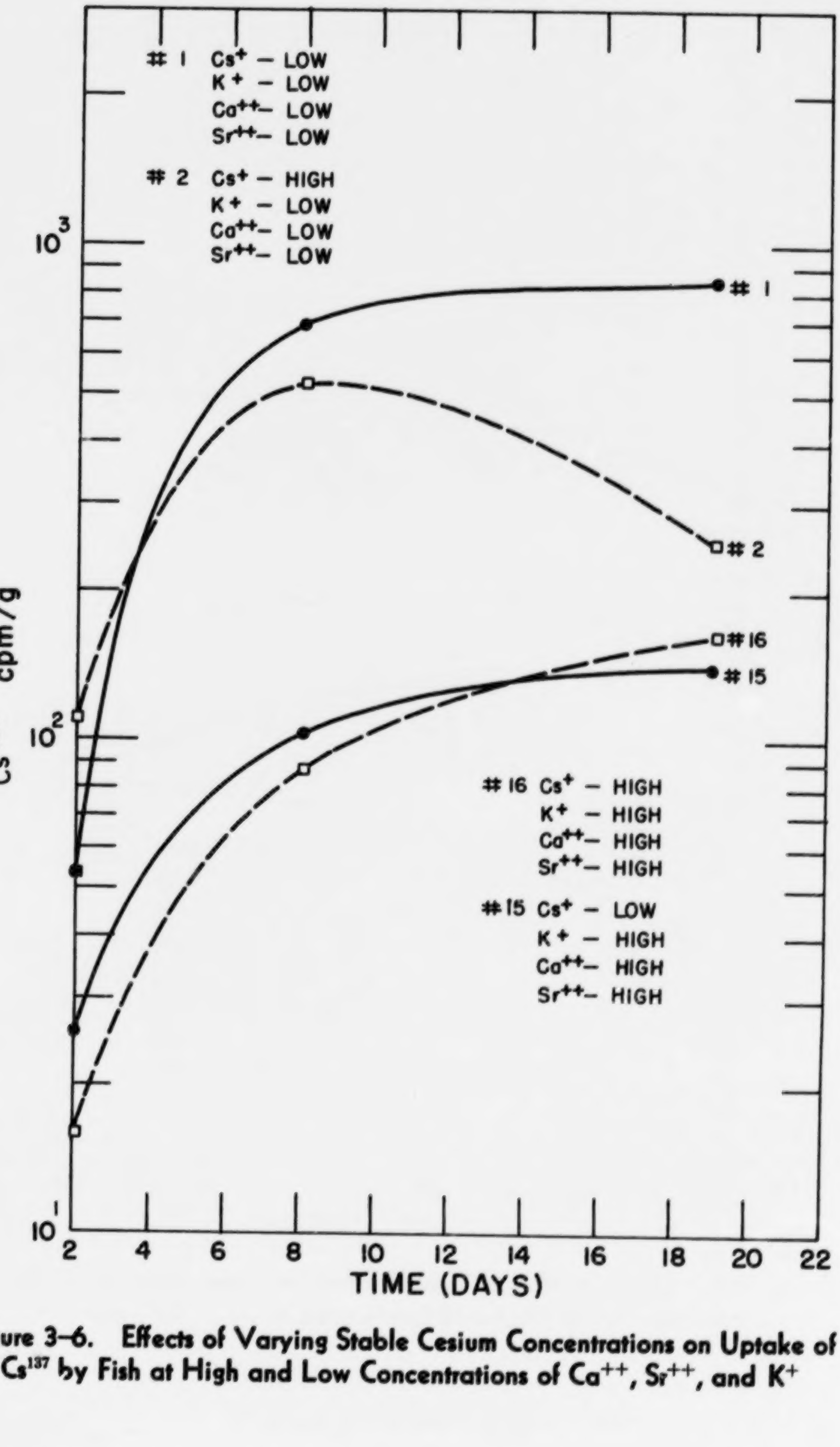

Figure 3–6. Effects of Varying Stable Cesium Concentrations on Uptake of Cs^{137} by Fish at High and Low Concentrations of Ca^{++}, Sr^{++}, and K^{+}

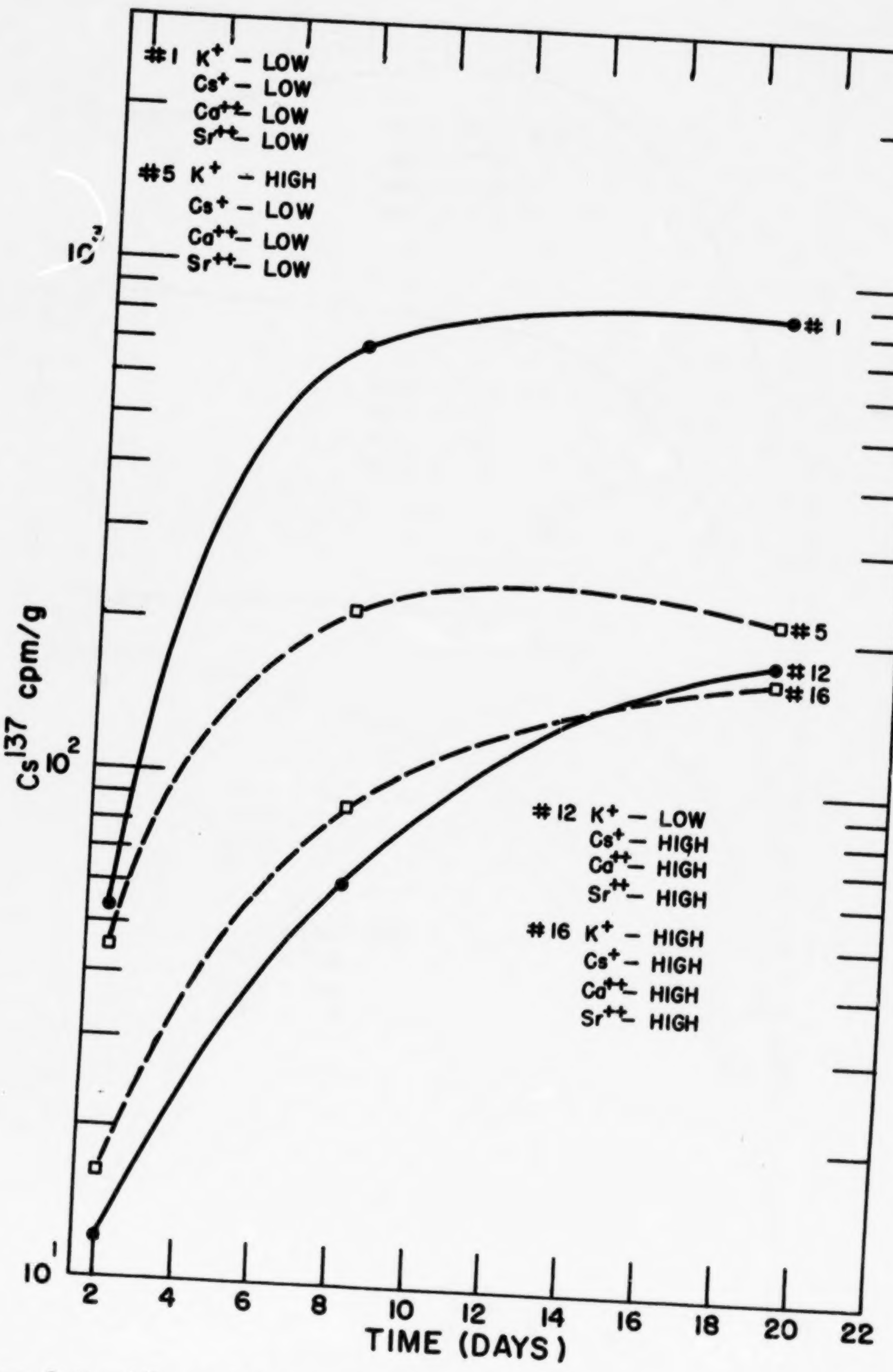

Figure 3–7. Effects of Varying Stable Potassium Concentrations on Uptake of Cs^{137} by Fish at High and Low Concentrations of Ca^{++}, Sr^{++}, and Cs^{+}

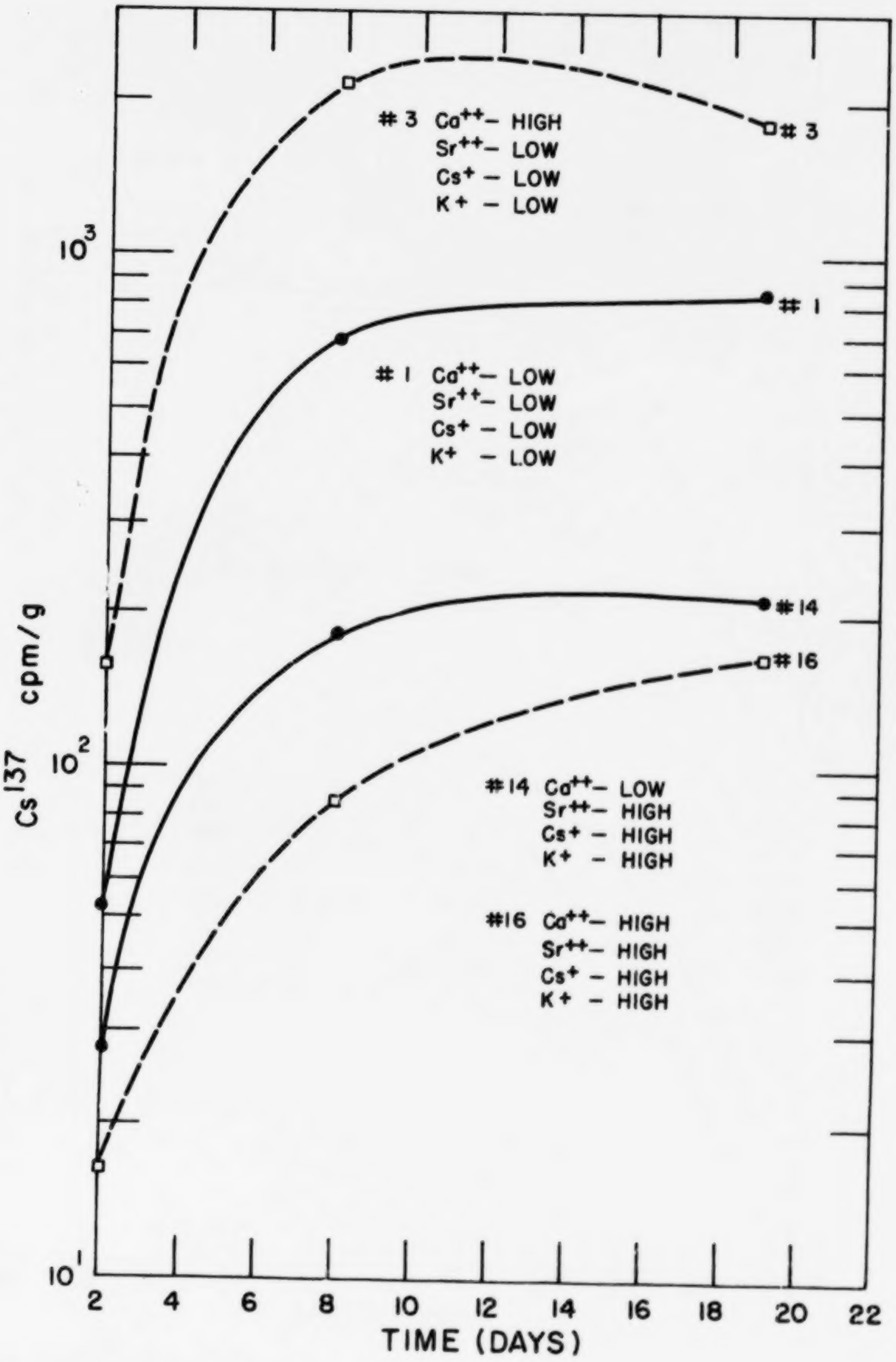

Figure 3–8. Effects of Varying Stable Calcium Concentrations on Uptake of Cs^{137} by Fish at High and Low Concentrations of Sr^{++}, Cs^{+}, and K^{+}

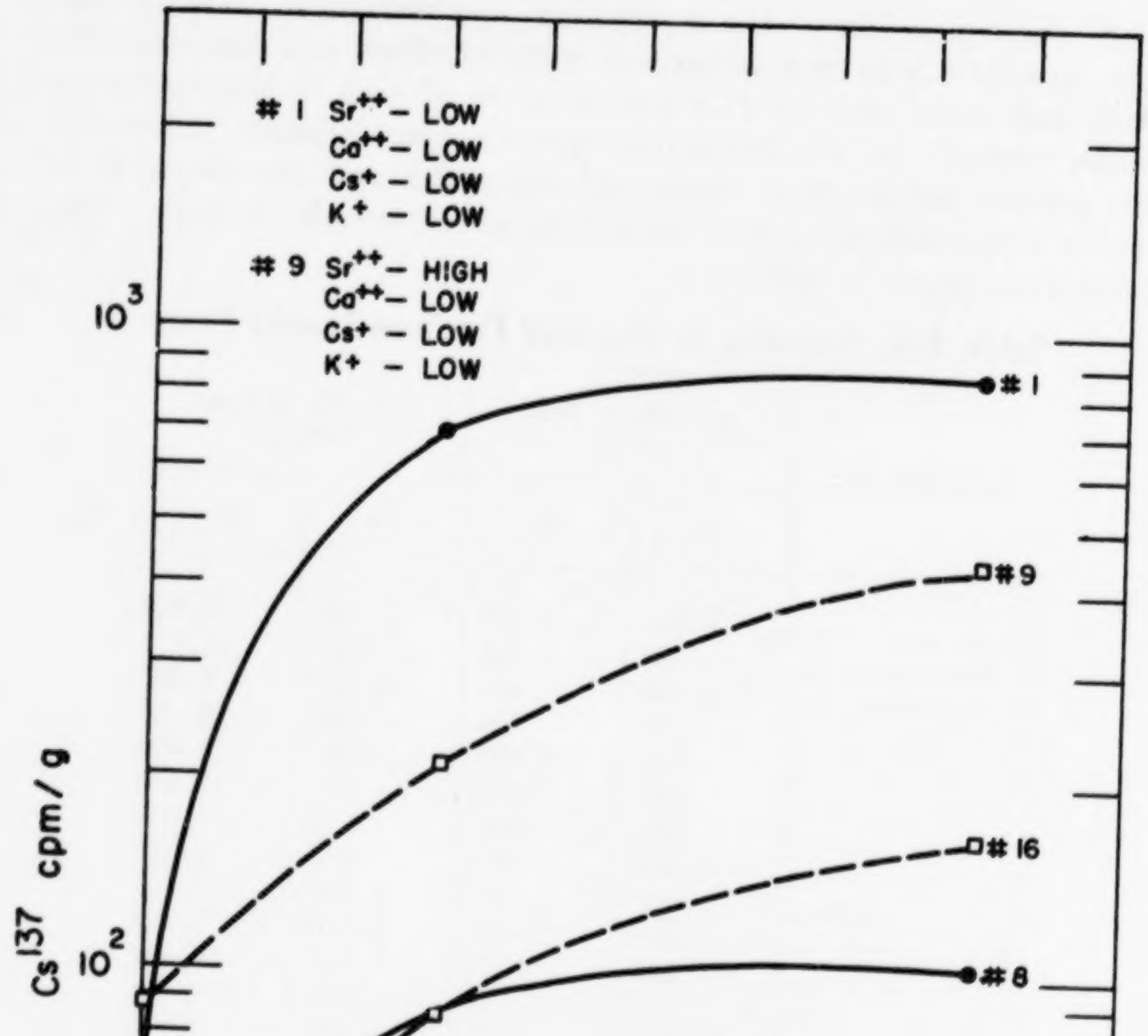

Figure 3–9. Effects of Varying Stable Strontium Concentrations on Uptake of Cs^{137} by Fish at High and Low Concentrations of Ca^{++}, Cs^{+}, and K^{+}

At the conclusion of the experiment, the remaining bluegills (approximately five in each aquarium) were sacrificed and dissected into flesh and bone, and the five similar parts of each combined before being counted on the 20-channel gamma spectrometer. However, the portion labeled bone contained the scales and the heads, from which it was difficult, if not impossible, to remove all the flesh. The results are shown in table 3-4.

Table 3-4. Activities in Dissected Fish from Uptake Study

Aquarium No.	Activity of flesh cpm/g [a]		Activity of bone cpm/g [a]	
	Cs	Sr	Cs	Sr
1	1, 059	4, 830	3, 506	15, 663
2	216	2, 543	1, 115	14, 221
3	2, 158	476	8, 695	2, 638
4	259	744	898	2, 393
5	205	2, 900	799	11, 492
6	182	2, 337	819	13, 885
7	154	339	502	1, 800
8	126	414	659	2, 867
9	407	1, 334	1, 510	4, 124
10	250	1, 242	1, 070	5, 165
11	1, 154	292	3, 883	2, 060
12	253	472	842	2, 170
13	165	1, 430	384	3, 475
14	109	793	899	5, 902
15	590	1, 671	977	1, 225
16	118	295	711	1, 690

[a] Wet weight.

To determine the effect of a particular stable ion on cesium or strontium uptake, the uptake values in counts per minute per gram were summed in two groups—those where the particular stable ion concentrations were high and those where they were low. The average effect was found by dividing summed values, the smaller into the larger.

The average numerical effects of the stable ion concentrations are shown in table 3-5.

The results confirm those of past experiments; that is, calcium, when in sufficient concentration, reduces strontium uptake. Thus, increasing the calcium concentration from 0.1 to 20 milligrams per liter caused a 75-percent reduction, on the average, in strontium uptake. Strontium concentrations varied over the same range, on the other hand, and caused only a 50-percent reduction, probably because of the ability of the organism to discriminate between calcium and strontium.

Strontium showed little or no effect on cesium uptake. However, calcium appeared to increase cesium uptake, so that at 20 milligrams per liter calcium concentration almost twice as much cesium was taken up as at a concentration of 0.1 milligram per liter. This phenomenon has not been explained. Possibly further study of the various interactions may explain it.

Cesium and potassium appear to have no effect on strontium uptake. Cesium or potassium concentrations, increased from 0.1 milligram per liter to 20 milligrams per liter, caused a decrease in cesium uptake of about 65 to 75 percent.

Table 3–5. Effect on Strontium and Cesium Uptake of Decreasing Stable Ion Concentrations

[From 20 mg/l to 0.1 mg/l]

Stable ion	Sr^{85}		Cs^{137}	
	Flesh	Bone	Flesh	Bone
Calcium	3. 7	4. 4	[a] (−)1. 8	[a] (−)1. 7
Strontium	1. 9	2. 5	1. 4	1. 6
Cesium	1. 5	[a] (−)1. 1	3. 9	2. 8
Potassium	1. 2	[a] (−)1. 1	3. 5	3. 7

[a] (−) indicates an inverse effect; that is, decreasing the stable ion concentration was accompanied by a decrease in uptake.

It has been suggested that a complicating factor in this experiment resulted from the fact that the fish were fed a balanced diet throughout the entire testing period, and that more meaningful results might have been obtained if the fish had experienced severe or chronic mineral deficiencies. To determine if this activity was taken in with the food, a duplicate experiment is now being undertaken in which the fish are not being fed.

The results of the fourth set of experiments are summarized in tables 3–6 to 3–12. The zero values are due to experimental error.

The standard deviation of each mean logarithm is listed as an index of its precision. To obtain approximately 95-percent confidence limits for a "true mean" log, add and subtract twice this standard deviation to and from the mean log. Then, to obtain 95-percent confidence limits for the geometric mean uptake expressed in picocuries per gram, take antilogs, to the base 10, of the confidence limits for the true mean log.

The "least significant difference" between means of logs is also listed. Any two mean logs are significantly different at the 95-percent probability level only if they differ by more than this least significant

Table 3–6. Activities in Experimental Solutions

[pc/ml]

Tank No.	Sr^{85}					Cs^{137}				
	Time in days					Time in days				
	1	6	13	20	27	1	6	13	20	27
1	74	34	56	53	50	199	87	122	106	98
2	100	37	68	117	55	227	92	166	241	120
3	136	72	128	112	97	255	138	234	213	199
4	125	55	102	91	78	257	116	233	220	191
5	99	38	59	48	46	243	107	185	176	150
6	103	91	69	68	56	272	283	249	233	214
7	135	59	114	111	70	262	115	226	222	185
8	135	122	103	120	100	265	224	240	267	196
9	119	104	89	78	62	204	212	197	187	159
10	124	58	102	91	79	231	121	242	215	197
11	132	60	94	107	93	231	111	241	201	179
12	136	69	131	119	105	269	144	279	274	251
13	117	100	88	93	78	240	227	212	244	216
14	126	56	97	100	83	266	124	239	263	207
15	153	64	123	135	92	279	140	240	254	202
16	115	117	103	20	79	268	265	245	703	222

Table 3–7. Activities in Experimental Fish

[cpm/g]

Tank No.	Sr^{85}				Cs^{137}			
	Time in days				Time in days			
	1	6	13	20	1	6	13	20
1	284	556	760	317	7	41	76	593
2	167	672	610	456	11	39	363	122
3	76	182	261	430	22	78	313	302
4	56	152	301	333	22	62	558	512
5	184	417	736	115	5	27	79	122
6	367	437	985	1, 436	6	23	158	181
7	144	204	229	340	4	21	122	97
8	65	175	320	258	10	26	61	59
9	80	267	473	477	33	101	126	416
10	250	403	567	684	11	61	204	329
11	35	136	255	277	16	28	74	207
12	59	129	323	380	5	26	160	227
13	91	322	773	804	27	33	63	169
14	174	390	734	736	25	37	95	99
15	120	142	255	576	6	42	152	218
16	50	94	243	341	6	17	48	199

Table 3–8. Activities in Experimental Snail Flesh

[cpm/g]

Tank No.	Sr^{85}					Cs^{137}				
	Time in days					Time in days				
	1	6	13	20	27	1	6	13	20	27
1	5, 696	7, 900	0	12, 973	[a] —	2, 247	60, 278	103, 566	[b] 9, 109	—
2	5, 833	5, 072	6, 167	36, 224	—	7. 513	31, 853	37, 221	6, 264	—
3	1, 428	2, 106	0	3. 341	2, 768	60	34, 937	55, 038	[b] 18, 511	65, 817
4	731	3, 220	0	10, 111	—	3, 209	7, 450	32, 095	[b] 6, 279	—
5	5, 510	4, 140	34, 350	29, 389	12, 593	2, 800	8, 780	20, 104	8, 029	17. 766
6	6, 986	11, 559	58, 098	819	—	3, 529	6, 325	20, 094	20, 151	—
7	634	2, 846	2, 749	—	—	892	11, 135	98, 908	—	—
8	1, 291	18, 492	2, 868	7, 748	9, 297	2, 243	6, 594	10, 173	12, 411	[b] 13, 303
9	2, 687	4, 361	0	12, 790	7, 188	4, 100	30, 858	35, 237	56, 554	40, 405
10	2, 940	14. 517	4, 908	—	—	3. 690	3, 989	2, 000	—	—
11	177	0	0	8, 610	1, 195	17, 760	3, 902	58. 129	75, 831	14, 090
12	865	2, 157	0	14, 703	5, 609	3, 929	20. 477	41, 095	9, 076	49, 118
13	3, 424	8, 913	7, 737	5, 777	492	2, 517	5, 171	7, 291	12, 673	1, 074
14	2, 132	3. 923	10. 306	6, 987	7, 681	1, 743	3, 581	13, 208	18, 143	10, 735
15	1, 106	3, 029	5, 717	—	—	1, 500	4, 363	10, 018	—	—
16	1, 247	1, 725	2, 393	5, 364	1, 484	2, 150	4, 244	6, 824	17, 980	2, 669

[a] Background levels.

[b] Snail shell washed out with distilled water.

Table 3–9. Activities in Experimental Snail Shells

[cpm/g]

Tank No.	Sr^{85}					Cs^{137}				
	Time in days					Time in days				
	1	6	13	20	27	1	6	13	20	27
1	3, 926	56, 080	14, 339	21, 782	14, 284	261	569	377	699	156
2	3, 820	5, 134	13, 917	21, 357	20, 727	120	86	410	425	194
3	1, 101	4, 114	18, 731	1, 394	4, 329	114	119	346	1, 273	378
4	783	521	7, 757	792	7, 501	36	684	186	449	195
5	1, 530	13, 353	94, 862	24, 034	75, 372	48	62	405	471	359
6	4, 291	51, 848	98, 224	23, 727	21, 897	100	90	322	478	223
7	1, 308	6, 602	3, 775	[a] —	—	50	109	96	—	—
8	857	5, 006	4, 591	4, 490	7, 119	50	28	104	774	1, 113
9	2, 554	7, 446	7, 225	11. 371	7, 942	86	141	288	889	247
10	1, 862	1, 098	2, 991	3, 856	928	1, 767	402	136	464	116
11	531	9, 618	12, 211	13, 603	15, 504	105	160	357	930	3, 124
12	1, 142	4, 932	8, 290	2, 346	37, 399	44	77	338	533	469
13	1, 205	14, 272	18, 950	12, 979	9, 456	65	656	0	619	263
14	2. 037	15, 431	795, 041	14, 690	26, 431	52	102	2, 004	471	158
15	1, 005	39, 715	506, 740	—	—	44	66	0	—	—
16	1, 234	14, 977	26, 932	14, 654	2, 998	65	65	94	499	269

[a] Background levels.

Table 3–10. Activities in Experimental Algae Solutions

[pc/ml]

Tank No.	Sr^{85}							Cs^{137}						
	Time in days							Time in days						
	1	6	9	13	16	20	23	1	6	9	13	16	20	23
1	79	52	52	38	43	38	37	14	0.8	0.8	12	3	3	8
2	73	58	57	40	51	43	39	486	326	302	210	271	253	242
3	140	129	126	96	108	93	91	8	7	6	4	2	5	2
4	181	146	83	110	120	110	106	542	441	255	165	179	164	383
5	105	68	69	37	50	39	36	491	325	323	203	265	227	214
6	88	[a] —	47	29	30	32	32	568	—	385	273	274	317	266
7	178	115	135	99	105	75	66	509	346	386	236	337	305	289
8	181	49	108	52	59	140	38	600	375	435	313	404	389	326
9	150	—	97	74	90	84	74	14	—	19	3	12	30	7
10	159	130	119	80	100	82	83	509	415	421	289	354	311	323
11	172	144	139	96	116	112	105	14	6	5	7	4	11	11
12	173	138	140	108	108	102	98	17	35	3	9	2	5	3
13	162	104	113	59	90	66	59	521	371	355	253	293	285	259
14	146	95	—	41	62	51	52	510	414	—	296	363	330	312
15	193	156	153	100	118	103	95	525	395	394	275	314	260	249
16	203	139	127	74	89	82	81	596	431	417	316	39[illegible]	363	317

[a] Background levels.

Table 3–11. Sr^{85} Activities in Experimental Algae

[pc/g]

Tank No.	Time in days						
	1	6	9	13	16	20	23
1	617, 901	358, 042	263, 408	262, 139	175, 372	150, 977	123, 333
2	558, 106	270, 707	237, 796	216, 974	184, 412	151, 557	162, 353
3	132, 235	132, 955	130, 035	100, 548	205, 805	83, 978	37, 553
4	64, 695	128, 166	105, 608	79, 209	86, 075	80, 301	83, 536
5	706, 321	406, 595	300, 122	247, 366	189, 519	172, 012	159, 420
6	524, 585	335, 128	215, 825	269, 677	214, 718	199, 063	190, 686
7	145, 040	147, 693	111, 405	75, 358	104, 972	111, 855	81, 371
8	219, 663	243, 599	146, 238	243, 427	248, 612	153, 143	191, 952
9	[a] —	168, 769	116, 786	141, 224	160, 711	131, 410	177, 199
10	181, 106	148, 242	119, 447	86, 890	89, 312	87, 770	59, 478
11	—	96, 376	93, 057	98, 796	67, 169	70, 589	78, 190
12	99, 251	—	80, 006	79, 524	80, 864	74, 076	57, 062
13	206, 729	163, 187	152, 951	141, 614	163, 299	140, 838	145, 238
14	203, 488	169, 682	386, 316	180, 817	159, 291	161, 489	93, 411
15	84, 622	76, 554	92, 437	85, 189	67, 859	67, 204	53, 660
16	116, 978	98, 089	72, 423	131, 166	107, 082	126, 800	68, 822

[a] Background levels.

Table 3–12. Cs^{137} Activities in Experimental Algae

[pc/g]

Tank No.	Time in days						
	1	6	9	13	16	20	23
1	514, 242	703, 067	527, 505	646. 142	1, 062, 124	5, 003. 096	6, 869, 664
2	485, 430	903, 312	1, 093, 686	1, 551, 053	1, 692, 144	1, 314, 904	1, 315, 567
3	6, 338, 667	4, 738, 945	2, 750, 069	2, 143, 921	5, 758, 474	2. 326, 519	2. 992, 429
4	125, 513	826, 667	874, 195	734, 195	1, 040, 403	1, 027, 054	714, 087
5	354, 707	889, 687	1, 041, 016	882, 343	794. 506	564, 391	558, 299
6	314, 876	428, 112	335. 249	526, 470	503, 479	500. 679	415, 993
7	347, 190	1, 094, 092	962, 539	875, 517	893, 048	763, 906	693, 749
8	220, 164	367, 122	424, 051	435, 413	381, 171	346, 317	370, 725
9	19, 421, 217	11, 363, 535	4, 507. 384	5, 751, 527	5, 906, 425	6. 203. 304	5, 834, 056
10	257, 126	630, 780	809. 008	866, 549	864. 000	522, 107	485, 214
11	19, 185. 016	3, 753, 596	6, 768, 538	12, 465, 538	5. 628, 338	2, 909, 373	6, 288, 788
12	223, 124	8. 917, 836	3, 237, 149	3, 121, 666	3, 977, 562	2, 725, 816	3, 709, 515
13	350. 430	557, 487	539, 473	530, 124	658, 489	604. 186	477, 464
14	184, 064	271, 970	820, 800	474, 889	452, 710	555, 180	350, 777
15	299, 290	673, 920	1, 439. 994	998, 698	1, 142, 916	867. 326	735, 005
16	421, 597	387, 305	357, 653	395, 556	433, 486	353, 661	336, 778

difference. This is the number referred to in making comparisons between means.

Since stable cesium had no significant effect on uptake of cesium-137, averages for whole fish were computed for both concentrations of stable cesium and for all 4 sampling days. These averages of eight values of $\log_{10}$ (pc cesium-137/g of fish) are listed below:

		K−	K+
Ca−	Sr−	2. 74	2. 52
	Sr+	2. 92	2. 68
Ca+	Sr−	3. 04	2. 43
	Sr+	2. 62	2. 55

Note: Standard deviation of each mean = ±0.063. Least significant difference between means = ±0.19.

Note that potassium has a significant effect on uptake of cesium-137 by whole fish in all solutions except those with Ca+ and Sr+.

Calcium has a significant effect with K−, but not with K+. Also, in the presence of K−, the effect of calcium is reversed with Sr− (where an increase in calcium caused increased uptake of cesium-137) from its effect with Sr+ (where increasing the concentration of calcium caused a decrease in uptake of cesium-137). Lowest uptake of cesium-137 seems to occur in the presence of Sr−, K+, independent of the concentration of calcium.

Potassium had little or no effect on uptake of strontium-85 by whole fish, so averages of log uptakes were computed for both potassium concentrations and for 4 sampling days. The averages of eight logarithms are listed below:

	Ca−		Ca+	
	Sr−	Sr+	Sr−	Sr+
Cs−	2. 93	2. 87	2. 70	2. 62
Cs+	3. 11	3. 02	2. 61	2. 57

Note: Standard deviation of each mean value $= \pm 0.05$
Least significant difference between means $= \pm 0.15$.

Effects of calcium are significant and consistent; increasing calcium reduced uptake of strontium-85 by 56 percent on the average. The effect was much greater when Cs+ was present than when Cs− was present. Stable strontium tended to decrease uptake of strontium-85, but the effect, if any, was too small to be distinguishable from experimental error. Stable cesium increased uptake of strontium-85 in the presence of Ca− but not in the presence of Ca+.

All four ions affected uptake of cesium-137 by algae, although stable strontium and calcium did so only occasionally. Averages of seven logs of uptakes, computed over 7 sampling days, are given in a four-way table below:

		Ca−		Ca+	
		Sr−	Sr+	Sr−	Sr+
Cs−	K−	6. 09	6. 87	6. 55	6. 83
	K+	5. 84	5. 72	5. 88	5. 90
Cs+	K−	6. 05	5. 78	5. 82	6. 42
	K+	5. 63	5. 60	5. 55	5. 58

Note: Standard deviation of means$= \pm 0.085$. Least significant difference between means$=0.25$.

Highest uptake of cesium-137 was obtained by use of Sr+Cs−K− (either Ca− or Ca+); lowest uptake was obtained with Cs+K+ (either Ca+ or Ca−, Sr+ or Sr−). Increasing the concentration of potassium reduced uptake of cesium-137 by 74 percent on the average. The reduction was significant in seven of eight cases, ranging from 44 percent to 93 percent, and tending to be less in the presence of Cs+ than in the presence of Cs−.

An increase in the concentration of stable cesium itself reduced uptake of cesium-137 appreciably, by 61 percent on the average, but by a greater amount with K− than with K+. An exception was that cesium had no significant effect on uptake of cesium-137 when both Ca− and Sr− were present. With Ca− and Sr+, reducing cesium increased uptake of cesium-137 markedly with K− but no effect was observed with K+. When stable strontium was increased, uptake of cesium-137 increased with K− but not with K+, except that when both K− and Ca− were present, no effect of stable strontium was found.

Increased concentration of calcium had no consistent effect on cesium-137 uptake, though it did cause a large (about 3.5-fold) increase in uptake of cesium-137 in the presence of either Sr−Cs−K− or Sr+Cs+K−. There was no indication of such an effect in any of the other six types of solutions.

All four ions had at least some effect on uptake of strontium-85 by algae, but the effects of potassium and cesium were not large. A table of average log uptakes, computed over all 7 sampling days, is given below:

		Ca−		Ca+	
		Sr−	Sr+	Sr−	Sr+
Cs−	K−	5.44	5.27	5.08	5.00
	K+	5.49	5.26	5.09	4.93
Cs+	K−	5.42	5.08	5.00	4.98
	K+	5.48	5.31	5.36	5.06

Note: Standard deviation of means = ±0.033. Least significant difference between means = ±0.10.

Highest uptakes were obtained in the presence of Ca−Sr−, and lowest uptakes with Ca+Sr+, irrespective of the concentrations of stable cesium or potassium.

Increased concentrations of calcium or stable strontium reduced uptake of strontium-85 by 49 percent and 35 percent, respectively, on the average.

Increased concentration of potassium caused approximately a twofold increase in uptake of strontium-85 in the presence of Ca−Sr+Cs+ or Ca+Sr−Cs+, but no similar effect occurred in the other six types of solutions.

Stable cesium had no consistent, appreciable effect on uptake of strontium-85. The effect of potassium, however, occurred only in the presence of Cs+, not in the presence of Cs−.

All four ions had at least some effect, in at least one type of solution, on uptake of strontium-85 by snail shells. A four-way table of average logs of uptakes, computed for samples on 5 different days, is given below:

		Ca−		Ca+	
		Sr−	Sr+	Sr−	Sr+
Cs−	K−	4.59	4.17	3.93	4.22
	K+	4.70	4.31	3.94	4.94
Cs+	K−	4.44	3.66	3.65	4.12
	K+	4.80	4.79	4.08	4.26

Note: Standard deviation of means = ±0.14. Least significant difference between means = ±0.42.

It is difficult to generalize about these results. For example, highest uptakes tend to occur in the presence of Ca−Sr−, but the very highest uptake is that obtained with Ca+Sr+Cs−K+.

Note, too, that increasing the concentration of stable strontium reduces uptake of strontium-85 in the presence of Ca−K− but actually increases uptake of strontium-85 (significantly in two of four cases) in the presence of Ca+. An increase in concentration of potassium increases uptake of strontium-85 significantly in three of eight cases. The effect of a change in concentration of stable cesium is erratic.

Experimental error for determinations of effects on cesium-137 uptake by snail shells was so great due in large part to two zero counts, that no significant effects could be found. Only the effect of potassium approached significance. Averages of 40 log uptakes, computed over 5 sampling days and two concentrations each of calcium, strontium, and cesium, are:

K−	K+
3. 38	3. 13

Note: Standard deviation of mean = ±0.08. Least significant difference between means ±0.25.

Both zero counts are contained in the average log uptake, 3.13 for K+, so that the significance of the effect of potassium is questionable, depending as it does on the validity of these two questionable values.

Seven zero counts were present in strontium-85 uptake in snail flesh, and the experimental error was large. Nevertheless, the table of averages of 16 logs for both calcium levels is given below. The number of zero counts included in each average is in parentheses.

	Ca−	Ca+
K−	3.89 (2)	2. 89 (5)
K+	4. 24 (0)	4. 00 (0)

Note: Standard deviation of means = ±0.16. Least significant difference between means = ±0.49.

Notice that the lowest uptakes are caused by large numbers of zero counts, which invalidate the apparent effect of potassium.

No zero counts were obtained with K+, however, so the reduction from 4.24 to 4.00 is valid, but not statistically significant. Since lack of significance might have been caused by the large error term, owing to zero counts, the data for K+ alone was considered. The standard deviation of means, determined from K+ data, was ±0.13 and the least significant difference was 0.37 so that no significant effect of calcium could be shown.

None of the ions significantly affected uptake of cesium-137 by snail flesh on any sampling day. On the average, increasing the concentration of calcium caused a 29-percent decrease in uptake of cesium-137 by snail flesh. The decrease was larger (57 percent) on days 6 and 13 than on days 1 or 20. Only the larger decrease was significant. Increasing the concentration of potassium also decreased uptake of cesium-137 by about 57 percent on days 6 and 13, but not even an indication of a decrease was observed on day 1 or day 20.

Averages of 32 log uptakes, computed over 4 sampling days and two concentrations of strontium, cesium, and potassium are:

K−	K+
5.01	4.81

Ca−	Ca+
4.98	4.84

Note: Standard deviation of means = ±0.06. Least significant difference between means = ±0.18.

Summary and Conclusions

General conclusions drawn from this experimental work should be of value for future studies. The effects of isotopic dilution must be taken into account, and specific activity must be used when discussing uptake of elements. Also, it is important to use levels of activity high enough so that counting efficiency and confidence limits allow valid interpretation of results.

Variations of other parameters affecting uptake of radionuclides produced results that indicate quite strongly the importance of stable constituents and laboratory controls. The greatest effect on the radionuclides strontium-85 and cesium-137 was that of isotopic dilution. On a specific activity basis this could be calculated from water concentrations. However, the greatest effect on the uptake of the element itself arises from varying the stable constituents.

Localizations in food chain organisms appear to depend on the trophic levels when they are based entirely on sorption from the water, i.e., it is highest in the algae. Other relationships are not clear.

From preliminary findings on localization within specific tissues, it appears that strontium-85 is concentrated in bones of fish and shells of snails. Cesium-137 apparently is concentrated by flesh of fish and snails.

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